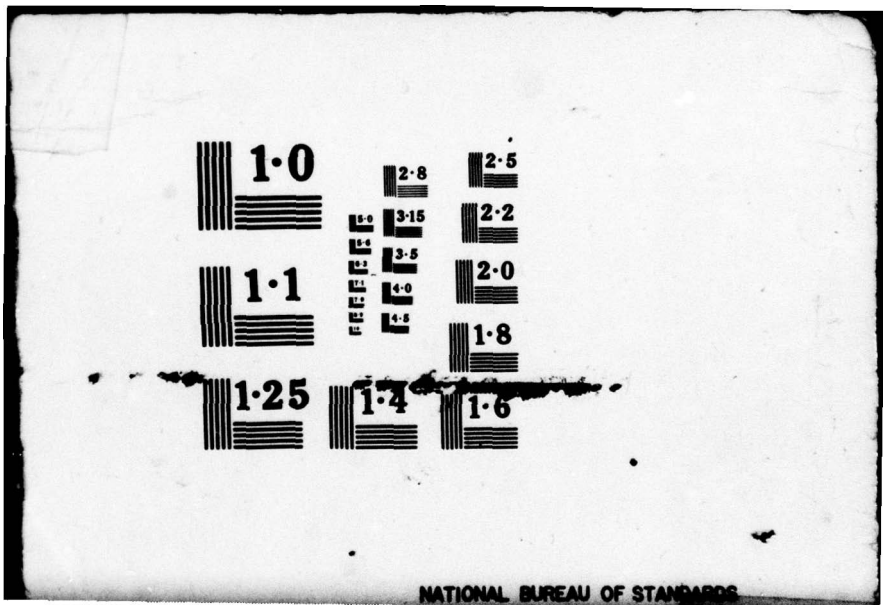
AD-A069 188 VERVE RESEARCH CORP ROCKVILLE MD F/G 17/2.1
ADVANCED COMMUNICATIONS SYSTEMS SUPPORT. AIR/GROUND RADIO ANTEN--ETC(U)
JAN 78 J HANSEN, A WEBSTER DOT-FA75WAI-570
UNCLASSIFIED VS-44 FAA-RD-78-11 NL

1 OF 3
AD
A069188




1·0
1·1
1·25
2·8
3·15
3·5
4·0
4·5
1·4
2·5
2·2
2·0
1·8
1·6
NATIONAL BUREAU OF STANDARDS

Report No. FAA-RD-78-11

LEVEL II

AD A069188

ADVANCED COMMUNICATIONS SYSTEMS SUPPORT

Air/Ground Radio Antenna System (Analysis and Evaluation)

J. Hansen and A. Webster
Verve Research Corporation
51 Monroe Street
Rockville, Maryland 20850

January 1978

Final Report

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

DDC
RECEIVED
MAY 31 1979
D

ACCESSION for
NTIS White Section X
DDC Buff Section
UNANNOUNCED
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

79 05 25 004

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-78-11		

4. Title and Subtitle	5. Report Date
Advanced Communications Systems Support Air/Ground Radio Antenna System (Analysis and Evaluation)	January 1978
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s)	
J. Hansen, A. Webster	VS-44
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Verve Research Corporation UniBank Bldg., 17th Floor 51 Monroe Street Rockville, MD 20850	11. Contract or Grant No. DOT-FA75WAI-570
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Advanced Communications Study; Research & Development Dec. 1976-Jan. 1978
Federal Aviation Administration Systems Research and Development Service 2100 Second Street., S.W., Washington, D.C. 20591	14. Sponsoring Agency Code ARD-220

15. Supplementary Notes

The submittal of this report completes the contractual obligations of Phase II, Task 2.2, Antenna System Analysis & Evaluation. It also incorporates the findings of Phase II, Task 2.1, Technical Planning and Support, for colocated air/ground communications facilities.

16. Abstract

Phase II is an in-depth antenna sub-ystem follow-on effort of the Phase I study. Phase I examined the requirements for an integrated air/ground communications facility, thereby establishing the basis for the detailed investigations of Phase II into advanced communications antennas.

The present study further develops the cost-effective Phase I plans to colocate radio facilities and to consolidate radio equipments within radio line-of-sight constraints. The analysis examines the performance capabilities and factors of several prevailing types of VHF and UHF antennas which appear at the offset to affect cosited antenna locations and colocated radios, i.e., to establish and demonstrate through appropriate examples, the separate influences of (1) available radio signal margins, (2) vertical antenna pattern lobing effects, (3) horizontal pattern distortion, (4) radio frequency interferences, and (5) aircraft antenna patterns.

It is concluded from experimental and analytical work that current RCAG facilities may use modified antenna systems to support up to 15 communications channels and to provide secondary and gap-filler coverages; that multi-couplers and combiners can be used very effectively; that RFI can be minimized; and that more extensive investigations appear justified in analysis, design, and development applications.

17. Key Words	18. Distribution Statement
Communications Air/Ground Radio Facilities VHF Radio System Design	Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	~~252~~ 248	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

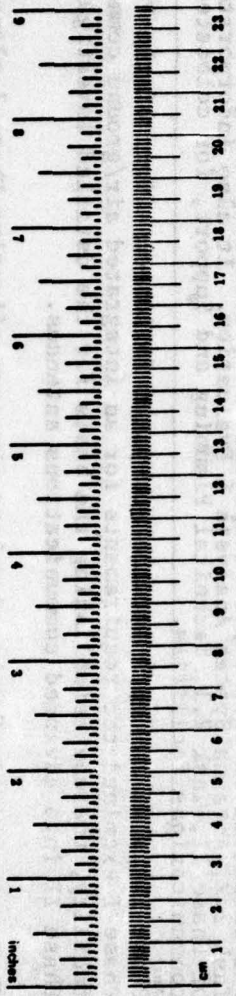
[redacted] 790504

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

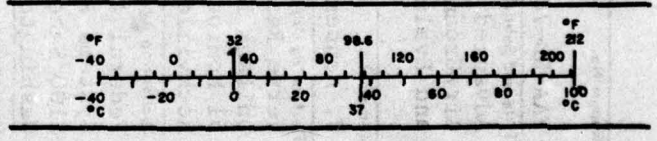
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGEMENTS

Verve Research Corporation would like to acknowledge the considerable guidance and active support contributed by both ARD-200 and ANA-430 during the period of this experimentally oriented program for analysis, test, and evaluation of antenna systems.

Mr. Newel Anderson, ARD-220, was directly responsible for the overall management and coordination of the program.

Mr. Jack Muller, ANA-330, coordinated the very valuable participation of NAFEC where the experimentation was carried out.

Mr. James Coyle, also of ANA-330, acted as Test Director for NAFEC and led the considerable effort in activating the test facalities and carrying out the numerous experiments.

Finally, particular appreciation is expressed to the FAA Project Manager, Mr. Leonard Bosin, ARD-220, who worked closely with the Verve staff and provided valuable technical inputs as well as overall administrative direction of the program.

CONTENTS

ACKNOWLEDGEMENTS iii

Part One BACKGROUND

1 EXECUTIVE SUMMARY 1-1

2 INTRODUCTION 2-1

3 CURRENT CENTER AREA OPERATIONS 3-1

3.1 Sector Airspace and Radio Coverage 3-1

3.2 Controller Operations 3-6

3.3 En Route ATC Antenna System Configurations. 3-11

4 AIR/GROUND RADIO LIMITATIONS 4-1

4.1 Radio Coverage 4-1

4.2 Antenna Pattern Distortions 4-5

4.3 Radio Frequency Interference (RFI) 4-6

4.4 Multiple Site Operations 4-8

Part Two ANALYSIS AND EVALUATION

5 RADIO ANTENNA CONFIGURATION SYSTEM ANALYSIS. 5-1

5.1 Introduction. 5-1

5.2 Typical Representation. 5-1

5.3 Power Budget. 5-8

5.4 Vertical Lobing. 5-12

5.5 Horizontal Pattern Distortion 5-18

5.6 Radio Frequency Interference (RFI). 5-38

5.7 Aircraft Antenna Patterns. 5-54

5.8 Summary 5-54

6 ALTERNATIVE ANTENNA SYSTEM CONFIGURATION ANALYSIS 6-1

6.1 Introduction. 6-1

6.2 Alternative Antenna Systems Configuration. 6-6

6.3 Summary. 6-23

7 EXPERIMENTAL EVALUATION 7-1

7.1 Introduction. 7-1
7.2 Antenna Test Program. 7-2
7.3 Experimental Flight Tests. 7-6
7.4 Experimental Setup. 7-6
7.5 Test and Analysis Procedures. 7-13
7.6 Flight Test Results 7-23
7.7 Conclusion. 7-55

8 ANTENNA SYSTEM CONFIGURATIONS FOR EN ROUTE APPLICATIONS . 8-1

8.1 General. 8-1
8.2 Radio Coverage 8-1
8.3 Radio Facility Colocation. 8-5
8.4 Antenna Systems 8-8
8.5 Multichannel Configurations 8-15

9 RECOMMENDED ADVANCED R&D PROGRAM FOR AIR/GROUND RADIO 9-1

9.1 General 9-1
9.2 Analysis, Test, and Evaluation of Antenna Systems 9-2
9.3 Combiner/Multicoupler Configuration Development 9-3
9.4 Field Applications and Assessments 9-4
9.5 Design and Development of an RCCS 9-5
9.6 Design and Development of an Air/Ground Radio Communications System 9-5

APPENDIX A A-1

APPENDIX B B-1

Part One

BACKGROUND

1. Executive Summary
2. Introduction
3. Current Center Area Operations
4. Air/Ground Radio Limitations

1

EXECUTIVE SUMMARY

1.0 INTRODUCTION

This final report covers the Phase II effort of a two phase program concerned with air/ground radio communications.

Phase I, "Study Requirements for an Integrated Air/Ground Communications Facility," examined air/ground radio from a system view and in particular analyzed the following subject areas:

(1) radio coverage,

(2) availability/reliability/maintainability,

(3) air/ground radio network switching and control,

(4) automated facility maintenance,

(5) automated ATC operations, and

(6) radio frequency environment.

The Phase I study concluded that colocation of radio facilities and consolidation of radio equipments into maximum-size clusters within the constraints of line of sight radio coverage is cost-effective. The introduction of automation and digitally controlled switching was recommended as a method of modernizing the air/ground system and minimizing the degree of manual operations for both maintenance and air traffic control. The radio coverage and radio frequency environment analyses indicated that the required coverage could be provided with fewer radio facilities and that the number

of antennas at FAA radio facilities could be reduced by the use of the TR switches and/or multicouplers. A comprehensive reliability analysis was conducted for the air/ground radio system and it showed that the radio propagation channel exhibits the lowest reliability relative to other subsystem elements in the system chain. On this basis, it was recommended that further analysis be conducted for the radio propagation channel and that continuing system studies be initiated for the following areas:

(1) control site radio access and control,

(2) maintenance facility and line concentration, and

(3) radio facility reconfiguration and integration.

Due to a lack of available funding, the Phase II program was limited to analysis and experimentation of the radio propagation channel as a first priority with particular concentration on the en route radio facility antenna systems.

The Phase II effort covered in this final report is a continuation of the Phase I program and deals with the expected effects of antenna system operations. To maintain a system perspective, a small, limited effort was also conducted to further investigate the advantages of radio facility colocation and its impact on radio coverage as well as ATC operations.

For the examination of antenna performance, the approach followed an attempt to separate the various perturbing factors that contribute to pattern coverage degradation and to develop methods of minimizing these effects.

Considerations involving the application of antenna systems were made within the context of air/ground radio system operations, since any modification to the antenna configurations now employed affects all other elements of the system.

The antenna system analysis treated the follow separable effects:

(1) available signal margin,

(2) vertical lobing,

(3) horizontal pattern distortion,

(4) radio frequency interference, and

(5) aircraft antenna patterns.

1.1 AVAILABLE SIGNAL MARGIN

The significant finding developed by analysis of the power budget for both VHF and UHF frequencies is that either modest positive signal margins (at VHF) or definite negative signal margins (at UHF) occur. The calculations are based upon free space losses and do not include the various degenerative effects contributed by pattern distortions and RFI. The signal margin can only be increased by an increment in power radiated or by utilizing gain antennas. It appeared, as a consequence of analysis of airspace sector coverage and the requirement for both redundant coverage (for high availability of service) and gap filler coverage (to fill in shadowed areas), that multisite operations are desirable for providing complete coverage over a particular airspace sector. With this approach, the signal margin now available is adequate, since more than one radio facility may be employed.

1.2 VERTICAL LOBING

The effects of vertical lobing were analyzed by calculating the expected lobe structure at VHF and UHF frequencies. At VHF, the primary lobe covers the operational airspace so that signal enhancement occurs within this band. At UHF, the vertical lobing structure places minimum signal nulls within the operational airspace and can degrade the expected signal by approximately 13 db. This situation reinforces the concept of utilizing multiple sites to obtain gapless coverage over the assigned airspace.

1.3 HORIZONTAL PATTERN DISTORTION

Distortions to the horizontal plane antenna pattern, for vertically polarized dipoles, occur due to interference contributions by radiating elements, in the vicinity of the antenna as well as far field objects, due to the asymmetry of the physical environment surrounding the antenna. The analysis of effects is complex and no satisfactory theory exists to fully predict the various perturbations. Theoretically developed results, for a single driver dipole in the presence of a parasitic dipole which

reradiates the propagated signal, show that the variation in signal can vary from 20 db nulls at .2λ separation to 2 db nulls at 5λ. A series of experiments were conducted to collect data describing the extent of distortion expected for representative FAA configurations. Signal nulls as great as -9 db were observed for antennas mounted in proximity to one another with spacings of λ/4. The limited data collected verifies that distortion occurs where magnitude is a decreasing function of antenna separation. It is evident that any metallic element such as tower railings, transmission lines, lightning rods, antenna mounts, or other antennas will reradiate sufficient energy to cause pattern distortion. The effects of horizontal pattern distortion are thereby minimized by reducing the number of antennas in proximity, by isolating the antenna from the tower structure, and by employing a center mounted configuration. Offset antenna mounting arrangements will exhibit a potential for creating directive interference effects that show up as horizontal pattern distortion. The practical application of these results points toward single or stacked antenna configurations using nonmetallic masts that are mounted on the geometric center of the tower platform.

1.4 RADIO FREQUENCY INTERFERENCE

An analysis was performed to investigate the effects of receiver desensitization, transmitter intermodulation, and receiver intermodulation, as the major sources of RFI. It was found that all three forms of RFI are potentially present in standard en route radio facility antenna configurations. Insufficient isolation exists to operate more than a single VHF plus a single UHF frequency on one tower (i.e., the standard present configuration). Multiple frequencies operated from different towers (spaced at 80 feet) will still be susceptible to RFI of the types defined above, depending upon frequency assignments and frequency separation. The minimization of RFI to acceptable levels can be achieved through the additional isolation provided by the employment of transmitter-combiner devices and by increasing the selectivity of the receiver pre-selector filter.

1.5 AIRCRAFT ANTENNA PATTERNS

It was assumed that the irregular antenna patterns exhibited by aircraft mounted antennas would contribute to signal degradation as a function of aircraft position and altitude. Variations of 6 to 9 db in the horizontal plane and up to 14 db in the vertical pattern are expected in representative fuselage mounted antennas. Limited experimentation during the flight testing phase did not provide verification of these numbers and further testing is necessary.

1.6 CONCLUSIONS

Based upon the analyses conducted and limited testing, a series of antenna configurations were studied that were variations of the standard en route (RCAG) facility configuration. The variations considered were the use of TR switches, stacked antennas, transmitter combiners, receiver multicouplers, and transmitter-receiver multicouplers. The conclusion of this phase of the analysis was that the current physical plant and layout may be retained for the en route facility by introducing transmitter combiners and receiver multicouplers that allow an expansion of activity from the current 4 channel (4 VHF and 4 UHF) maximum capacity to a 15 channel capacity utilizing 4 stacked (1 VHF and 1 UHF) antennas (1 per tower platform).

The second phase of the program was devoted to a series of experiments conducted at the antenna range and the experimental RCAG facility located at NAFEC in Atlantic City. The tests conducted included free space antenna measurements for a group of both FAA inventory and independently procured antennas, horizontal pattern measurements (already described), and a series of flight tests simulating air operational environment.

The individual antenna measurements for free space patterns conducted on the antenna range basically confirmed the manufacturer's specifications for VSWR, gain and free space pattern. Since most of the antennas tested were broad band, pattern irregularities appeared at the band limits for a number of the antennas tested. A complete report describing the free space antenna measurements will be issued by NAFEC in the near future. For the purposes of this program, it was concluded that the specific antenna employed did not exert a substantial impact on system performance. (There were some exceptions to this conclusion that involved particular antennas that did not exhibit the performance specified.)

The most desirable attribute is signal gain (omnidirectional gain) and this is obtained at considerable increments of both cost, physical size, and complexity. The use of directional antennas was considered, but the desired use of multicouplers encourages the employment of omnidirectional common antennas. The series of flight tests were conducted for both radial and orbital flights centered on the NAFEC experimental RCAG. A number of antenna configurations were tested that included single, multiple and stacked antennas at both VHF and UHF frequencies. The results indicated that a center mounted, vertically polarized, 0 to 1 dbi dipole antenna with a nonmetallic mount exhibited the best overall performance. The flight testing phase was curtailed due to scheduled completion of the program and further validation testing is recommended. From the initial data collected, the following conclusions are advanced:

(1) Single, center mounted antennas appear to contribute to a more regular horizontal pattern.

(2) Vertical extension of antennas above the tower, mounted on non-metallic mounts reduces pattern distortion.

(3) Aircraft position and altitude did not appear to contribute to antenna pattern degradation (testing was limited).

(4) The current FAA standard configuration (transmitting swastika and receiving coaxial dipole) is substantially outperformed by a simple broad band vertical dipole.

(5) The procured gain (omnidirectional) antennas offer no significant advantage over the simple dipole antennas.

The final phase of the program consolidated the analytical and experimental results and examined the impact on the air/ground system particularly with regard to radio coverage and colocation. The results combine to allow formulation of a concept for air/ground radio operations in which:

(1) The current RCAGs are used with modified antenna configurations that will provide up to 15 channel capability.

(2) The RCAGs are configured to support one another by providing not only their own assigned primary radio coverage, but also secondary coverage and gap filler coverage to adjacent areas.

(3) RACGs with the additional channel capability can be employed to provide colocation facilities for both terminal area and flight service channels when warranted by their location.

(4) Transmitter-combiners and receiver multicouplers, will reduce the number of required antennas from 60 to 4 (stacked antennas) for a 15 radio channel (15 UHF + 15 VHF) capability.

(5) The use of combiners and more selective front end filters will minimize RFI effects.

The results obtained thus far from Phases I and II of the Air/Ground Communications Program require a substantial additional effort to achieve an implementation program for both the Radio Communications Control System (RCCS) and the Radio Communications System (RCS).

Verve has identified the following areas that require a more extensive effort to complete the overall program:

(1) continued test, analysis and evaluation of antenna systems,

(2) combiner/multicoupler configuration development,

(3) field application and assessment,

(4) design and development of an RCCS, and

(5) design and development of an RCS.

2

INTRODUCTION

This study analysis and experimentation represents a continuation of a Phase I Study performed for a universal air/ground radio facility. One of the findings of the Phase I Study was that the air/ground propagation path exhibited the lowest reliability (approximately 0.90) of the various segments that make up the air/ground system. Another result of the study demonstrated that colocation of radio facilities for performing the different air/ground radio functions was both technically feasible and cost effective.

The Phase II effort, which is described in this report, concentrated on antenna systems and colocation as a follow-up to the Phase I results by accomplishing a program of analysis and experimentation.

The approach utilized for the program involved an examination and evaluation of antenna systems in the context of both current operations and those that appear likely for the future. The FAA's National Airspace System (NAS) must continuously grow in capability to respond to increasing air activity. The current radio facility configurations are limited in growth potential because of the finite number of available radio frequencies that may be assigned on a noninterfering basis, and because of the growing congestion of antennas within a confined area.

An additional limit to continued growth is the concern for increasing maintenance costs. A maintenance growth management program has been instituted within the FAA to constrain the uninhibited increase of maintenance costs associated with what is essentially a labor intensive activity.

The major objective in the consideration of antenna systems is to achieve a responsive air/ground radio system that meets radio coverage requirements and, at the same time, effects a minimization of discrete radio facilities. This present study explores the alternate methods by which a radio facility capability (expressed as a maximum number of radio channels) can be expanded without adding more facilities.

The consideration of antenna systems is a key element in facility expansion since current configurations employ a one to one relation between antenna and radio transmitter or radio receiver. Therefore, large numbers of assigned radio channels result in a correspondingly large number of antennas mounted in close proximity to one another.

The study and analysis, augmented by selected experimentation carried out at the NAFEC Facility, concentrates on development of multichannel configurations that allow considerable growth and also eliminate or minimize the degradation effects of signal loss; antenna pattern distortions and radio frequency interference.

Two additional factors impact current ATC operations. First, the airspace sector coverage, particularly for low altitude sectors, exhibit gaps in coverage due to terrain shadowing, pattern distortion and other related effects. Second, the very high availability-of-service requirement for air/ground radio support to ATC operations necessitates backup coverage. This is presently supplied by the Backup Emergency Communications (BUEC) configuration that falls considerably short of 100 percent redundancy. The study and analysis treats these two factors and recommends flexible configurations based upon the concept of multichannel universal radio facilities that provide primary coverage over an assigned airspace sector as well as secondary and gap filler coverage over adjacent airspace sectors.

A significant amount of effort was expended in experimentation to verify and validate some of the concepts developed. However, the limited period of the contract coupled with various delays in the procurement of test antennas and instrumentation, did not allow as extensive a sample of experiments as initially planned.

The following chapters of this report present both the analysis and experimentation carried out for antenna systems. The results are interpreted and a multichannel configuration for en route facility application is developed. Finally, a series of recommendations are listed for further analysis, system development, and field experimentation.

3

CURRENT CENTER AREA OPERATIONS

3.1 SECTOR AIRSPACE AND RADIO COVERAGE

Each center area with its associated ARTCC divides the assigned airspace into sectors for purposes of air traffic control. Exhibit 3-1 defines the sector service volume dimensions currently used by the FAA. ATC operations assign one ATC team per sector so that actual sector size is determined by the acceptable load of air activity that an air traffic controller may handle. The controller is responsible for the regulation of air activity within his sector boundaries and exact control via his assigned radio frequency channel. As shown in Exhibit 3-1, the airspace is partitioned into the two main segments of high altitude and low altitude airspace.

Within these major divisions, further subdivisions are made on the basis of radio coverage and amount of air activity. Sector boundary limits are impaired by several conditions. First, the total volume of airspace is limited by the line-of-sight propagation conditions of the radio system. For low air activity sectors that do not require the full-time attention of an air traffic controller, the tendency is to increase the size of the sector; this is the practice in some areas of the Rocky Mountain Region. When the sector size exceeds line-of-sight conditions, a second radio facility is required. This complicates operations since the controller must now communicate via two different radio facilities using the same radio frequency.

For high activity sectors, as in the Eastern Region, the sector size is made smaller to maintain an acceptable work load on the controller. However, at some point, the number of hand-offs of air traffic will increase in frequency so that

Exhibit 3-1

SECTOR SERVICE VOLUME DIMENSIONS

SERVICE	Service Altitude (feet)	Service Range (Nautical Miles)
Precision Approach Radar	*5,000	25
Helicopter Control	*5,000	30
Local Control and VFR Radar Advisory	*10,000	30
Approach Control (Radar or Manual) & ATIS	**25,000	60
Departure Control (Radar or Manual)	**20,000	60
Low Altitude En route	**18,000#	60
High Altitude En route (VHF)	***45,000	150
High Altitude En route (UHF)	75,000	200

*Above terrain
**Above MSL
***Altimeter standard pressure setting (29.92)

#. Service is provided to 24,000 feet at regional discretion case-by-case basis.

the controller's time is expended in accepting and initiating hand-offs. Sector shapes are influenced by the desirability of keeping aircraft under the control of a single controller during the traverse of airspace intersections and during high cockpit activity (as in altitude transitions and maneuvers).

Within these constraints, sectors are developed and require air/ground radio communications throughout the sector volume.

Exhibit 3-2 shows the location of the en route radio facilities for the Western Region with ARTCC's at Fremont and Palmdale. The remote radio facilities (RCAGs) indicated are placed to provide radio coverage for all sectors (both high and low altitude) in the region.

Although it is desirable to extend radio coverage to ground level for communications throughout the airspace, the FAA requires that radio coverage for en route operations include the minimum en route altitude (MEA) defined by the network of airways. The MEA will vary as a function of the local terrain to provide adequate clearance above mountains and other obstacles.

Exhibit 3-3 shows a low altitude sector within the Oakland Center Area (LAT Sector 17). The sector boundary and the required radio coverage, which extend beyond the sector boundary, are shown. The specified airways are also shown and indicate the MEA's along each route. The air traffic controller for this sector requires air/ground radio coverage that includes the MEA's shown, and extends up to 24,000 feet (which is the ceiling for low altitude coverage).

Because of the possibility of a single radio site failure, the concept of Backup Emergency Communications (BUEC) was introduced in 1970. The Oakland Center Area was the first test bed for the BUEC implementation program. BUEC was designed to provide controllers with frequency redundancy in the event of RCAG failure. The BUEC system represents a positive step toward air/ground radio communications automation and it incorporates automatic selection and tuning of remotely located transceivers.

Exhibit 3-2

REMOTE AIR/GROUND RADIO FACILITIES

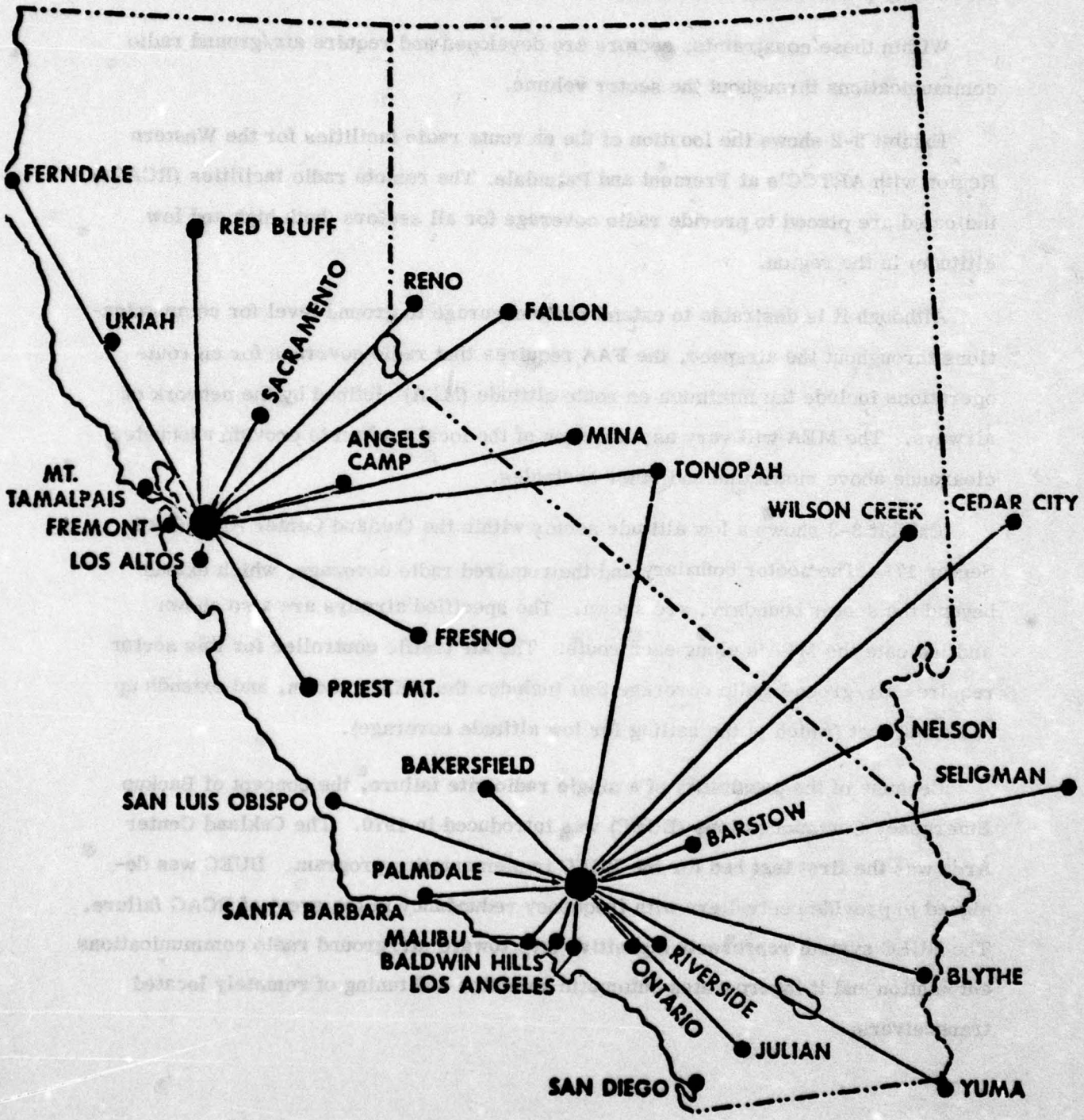
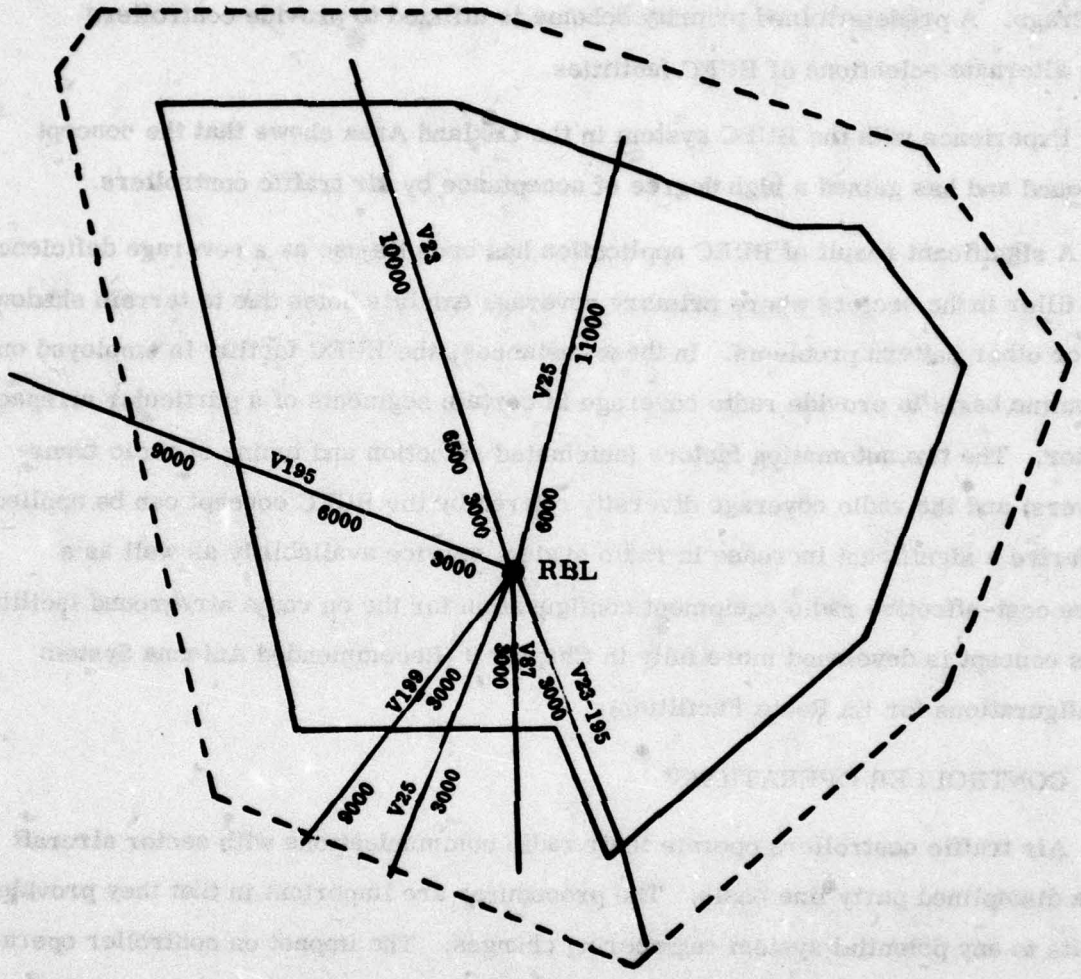


Exhibit 3-3

ZOA SECTOR 17 COVERAGE AND AIRWAYS



Sector Boundary

Required Coverage

The initial use of BUEC focused on employing the Long Range Radar (LRR) facilities as backup sites for providing redundant radio coverage for the en route (RCAG) facilities. Since the LRRs are displaced from the RCAGs, the backup coverage is not completely redundant, particularly for low altitude sectors.

Exhibit 3-4 shows an arrangement of BUEC sites and the expected percentage coverage. A predetermined priority scheme is utilized to provide controllers with alternate selections of BUEC facilities.

Experience with the BUEC system in the Oakland Area shows that the concept is sound and has gained a high degree of acceptance by air traffic controllers.

A significant result of BUEC application has been its use as a coverage deficiency gap filler in the sectors where primary coverage exhibits holes due to terrain shadowing or other pattern problems. In these instances, the BUEC facility is employed on a routine basis to provide radio coverage in certain segments of a particular airspace sector. The two automation factors (automated selection and tuning of radio transeivers) and the radio coverage diversity offered by the BUEC concept can be applied to derive a significant increase in radio system service availability as well as a more cost-effective radio equipment configuration for the en route air/ground facilities. This concept is developed more fully in Chapter 9 (*Recommended Antenna System* Configurations for En Route Facilities).

3.2 CONTROLLER OPERATIONS*

Air traffic controllers operate their radio communications with sector aircraft on a disciplined party line basis. The procedures are important in that they provide limits to any potential system engineering changes. The impact on controller operations must be carefully considered relative to work load, complexity, and service availability. There are several aspects of controller operations that influence the engineering design of radio facilities and antenna systems:

(1) Dual Frequency Operations. Although a controller is assigned a single radio channel for sector radio communications, the actual

---

*Detailed controller operations are presented in the Phase I Report, FAA-RD-76-154, May 1977.

Exhibit 3-4

BUEC COVERAGE

Low Altitude

Sector	BUEC Site	Priority	Percentage Coverage	RCAG Site	Channel
10	PRB	1	100%	Priest	7
	OAK	2	40%		
11	PRB	1	90%	Fresno	22
	OAK	2	30%		
12	PRB	1	80%	Fresno	19
	SAC	2	20%		
13	SAC	1	75%	Angels Camp	14
	OAK	2	60%		
14	SAC	1	80%	Angels Camp	13
	OAK	2	75%		
15	SAC	1	100%	Angels Camp	15
	OAK	2	80%		
16	RNO	1	100%	Reno	30
	FIX	2	90%		
	FLX	1	80%	Tonopah	35
	RNO	2	70%		
17	RBL	1	90%	Red Bluff	25
	SAC	2	50%		
18	UKI	1	*60%	Mt. Tamalpais	43
	SAC	2	*60%		
22	OAK	1	100%	Mt. View	2
	ARTCC	2	70%		
23	ARTCC	1	100%	Mt. View	3
	*SAC	2	70%		
24	OAK	1	100%	Mt. View	1
	*SAC	2	100% est.		
	ARTCC	3	90%		
25	ARTCC	1	80%	Angels Camp	9
	*SAC	2	100% est.		
26	SAC	1	100%	Mt. Tamalpais	45
	UKI	2	70%		
	RBL	3	40%		
27	OAK	1/3	95%	Mt. Tamalpais	44
	UKI	2	85%		

*This sector has dual frequencies, second site located at Ferndale. Coverage indicated is percent of sector.

High Altitude

Sector	BUEC Site	Priority	Percentage Coverage	RCAG Site	Channel
31	RBL	1	100%	Red Bluff	24
	SAC	2	85%		
	UKI	1	80%	Ferndale	29
	RBL	2	*75%	*% of area covered by Ferndale RCAG.	
32	RBL	1	100%	Angels Camp	46
	SAC	2	100%		
	*RCO	3	90% est		
33	FLX	1	95%	Fallon	31
	*RNO	2	100% est		
	*SAC	3	50% est		
34	FLX	1	90%	Tonopah	34
	RNO	2	80%		
42	OAK	1	80%	Angels Camp	11
	SAC	2	95%		
43	PRB	1	100%	Fresno	21
	*SAC	2	80%		
	*OAK	3	70%		
44	OAK	1/3	(1) 85%	Priest	8
	ARTCC	2	90%		
45	PRB	1	100%	Fresno	18
	OAK	2	95%		
			Oceanic High and Low		
47	OAK	1	98%	Mt. View	4
	*SAC	2	60% est		
	ARTCC	3	70%		

(1) This site preferred for first site priority to cover marginal area of coverage from RCAG site in northern portion of sector.

Key: ARTCC — Air Route Traffic Control Center
Scarper LRR (OAK) — Oakland
Sacramento (SAC) — Sacramento
Paso Robles (PRB) — Paso Robles
Red Bluff (RBL) — Red Bluff
Fallon (FLX) — Fallon
Vista Peak (RNO) — Reno
Ukiah (UKI) — Ukiah

configuration involves the operation of two radio frequencies (a VHF and a UHF) in order to accommodate both civil and military users of the airspace. Controllers will operate in either a split channel mode (independent telephone lines for each radio frequency) or in a paired or selective mode (a single telephone line). When using paired operations, the controller keys both VHF and UHF transmitters for all communication transactions. While operationally convenient, the dual keying creates an additional unnecessary source of radio frequency interference. In the split operation mode, the controller must select between VHF and UHF, depending on the radio frequency the aircraft calls in on. Additionally, in the split operation mode, the civil and military aircraft are also split and cannot monitor all air/ground radio transactions. Thus, the controller, for example, must monitor his UHF frequency assignment while conducting communications at VHF, since a military aircraft may call in.

(2) Call in Procedures. Normal procedures for air traffic control provide for radio contact to be initiated by the aircraft as it enters the sector, after handoff by the preceding controller. This, together with the requirement to continually monitor all assigned radio frequencies (including the emergency radio frequency) to respond to requests for assistance, means that all air/ground radio channels (for ATC) are dedicated, full period circuits. The fact that a majority of radio channels exhibit a low duty cycle or low utilization, would indicate that common user lines or circuit sharing techniques would result in substantiated cost savings. This concept, explored in the Phase I Report of the current contract, involves the implementation of a signaling capability in the aircraft (similar to the selective calling feature employed by the airlines). The implementation of the Discrete Address Beacon System (DABS) program as presently scheduled by FAA will provide

a digital signaling capability via the data link portion of DABS.

(3) Multiple Site Operations. For large airspace sectors with low air activity; or for sectors that require an augmentation of coverage from an additional radio facility, the FAA employs two or more radio facilities to obtain the required radio coverage. Exhibit 3-5 shows an example in the Oakland Center area, where, for coverage of Sector 16, three facilities at Reno, Fallon, and Mina are employed. The difficulty with this form of operation is that the three facilities are communicating on an identical sector radio frequency. In order to avoid radio and audio interference between the signals, it is necessary to utilize a single facility at any given time. For transmission (i.e., ground to air) the simultaneous radiation of three transmitters would result in a minimum of a six path (direct and reflected) multipath signal of the aircraft antenna. For received signals, each detected audio output must be remoted back to the Oakland ARTCC. Since the audio paths may suffer differential delays on the order of 25 to 100 milliseconds, the resultant mixed audio will exhibit phase distortion. The alternative is to selectively activate the appropriate radio facility for communications covering a partial area of the airspace. This procedure requires knowledge of aircraft position and places an additional work load on the controller.

(4) Quality Control and Maintenance. Current ATC communications are carried out in the voice mode with voice quality or intelligibility determined by a subjective judgment of the specific controller. If a controller cannot interpret received messages, he has the option of a) selecting a backup radio equipment; b) selecting a

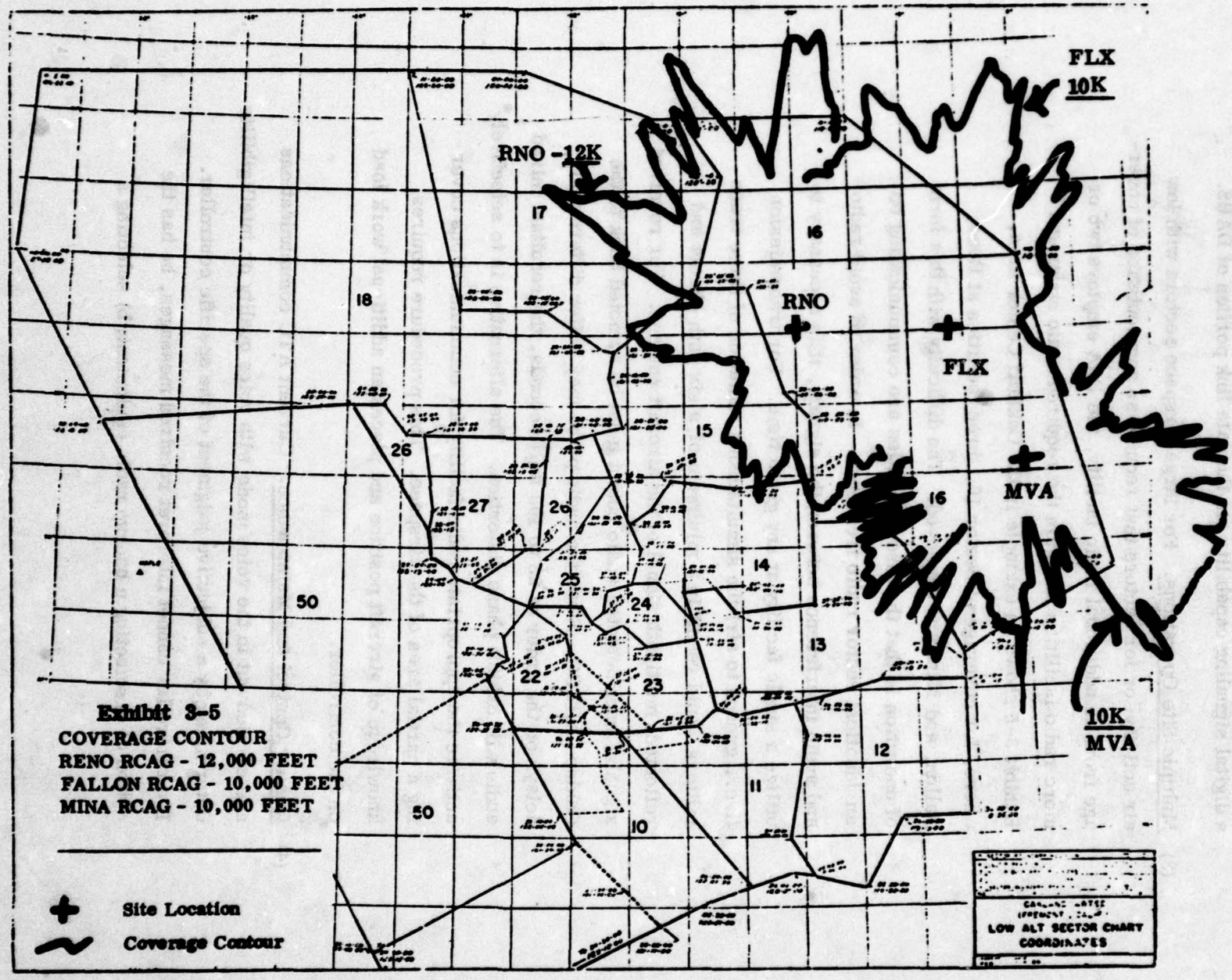


Exhibit 3-5
COVERAGE CONTOUR
RENO RCAG - 12,000 FEET
FALLON RCAG - 10,000 FEET
MINA RCAG - 10,000 FEET

backup remoting telephone service; or c) selecting a second radio facility (i.e., BUEC). This procedure leads to fault isolation problems for the maintenance activity since many of the faults cannot be readily identified as to cause and location. For example, a defective aircraft transmitter can create a communication difficulty that is not remedied by any of the actions listed above. While it is possible to monitor the characteristics of both the radio equipments and the telephone lines by employing technical control procedures, such procedures do not assure that the voice quality is acceptable or even useable. It appears that the subjective judgment of the controller will continue to be the primary method for assuring voice quality on air/ground communication channels.

The discussion of controller operations demonstrate some of the complexities involved in attempting to simplify and automate the procedures. The "one push button" concept for air/ground communications is an ideal approach that seems impractical, at present, for implementation.

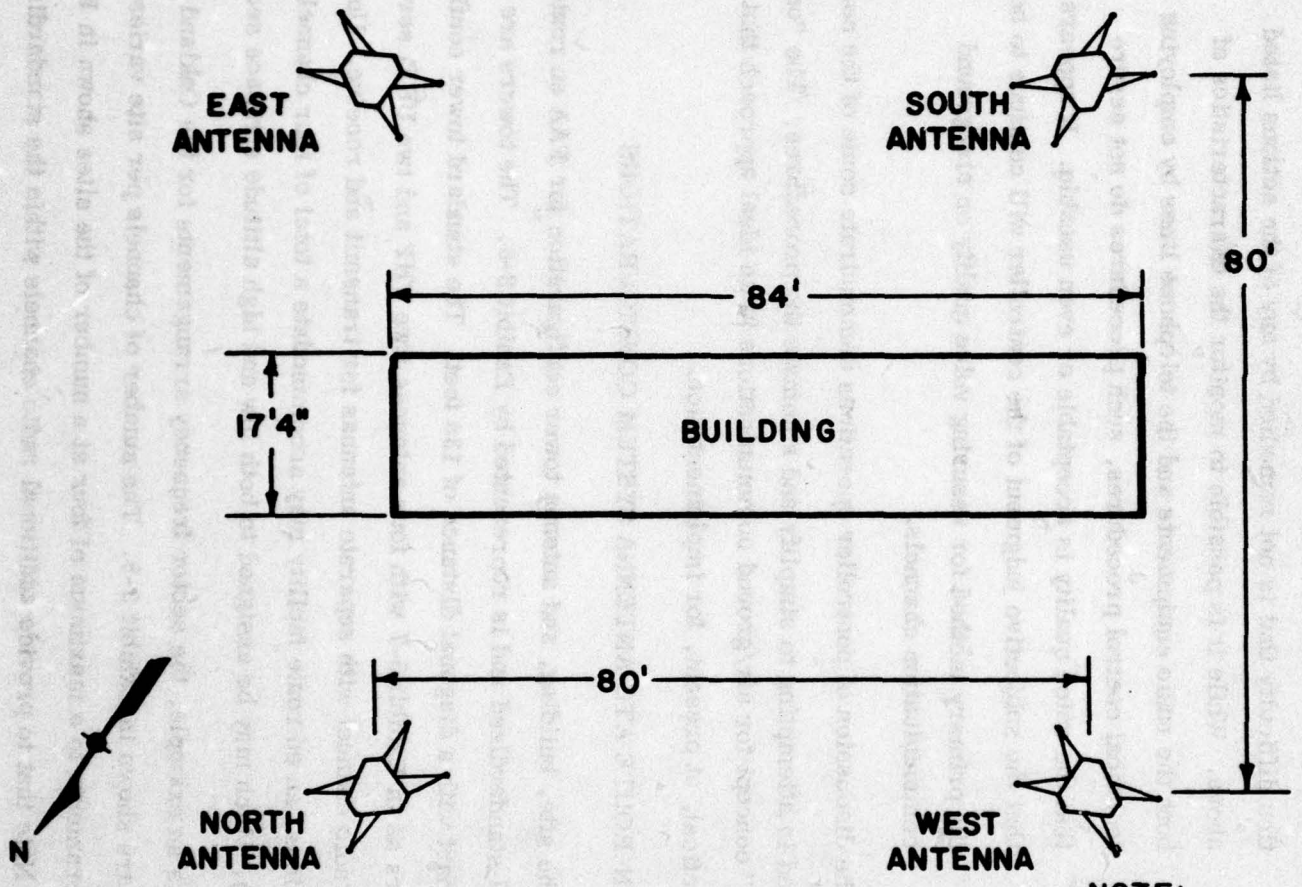
3.3 EN ROUTE ATC ANTENNA SYSTEM CONFIGURATIONS

The site, building, and antenna tower configuration for FAA en route facilities is well standardized and is represented by Exhibit 3-6. The towers are placed 80 feet apart with a diagonal distance of 138 feet. The standard tower configuration appears as in Exhibit 3-7 with four antennas (two VHF and two UHF) serving one ATC radio channel with separate antennas for transmit and receive. Under normal conditions, an en route facility may accommodate a total of four channels (one per tower), which may be assigned to both low and high altitude airspace sectors.

As an example, the sector frequency arrangements for the Oakland Center Area are shown in Exhibit 3-8. The number of channels per site varies from one at Sacramento to a maximum of four at a number of the sites shown in Exhibit 3-8. Note that to provide additional radio channels within the standardized configuration

Exhibit 3-6

RCAG BUILDING AND ANTENNA TOWERS PLAN



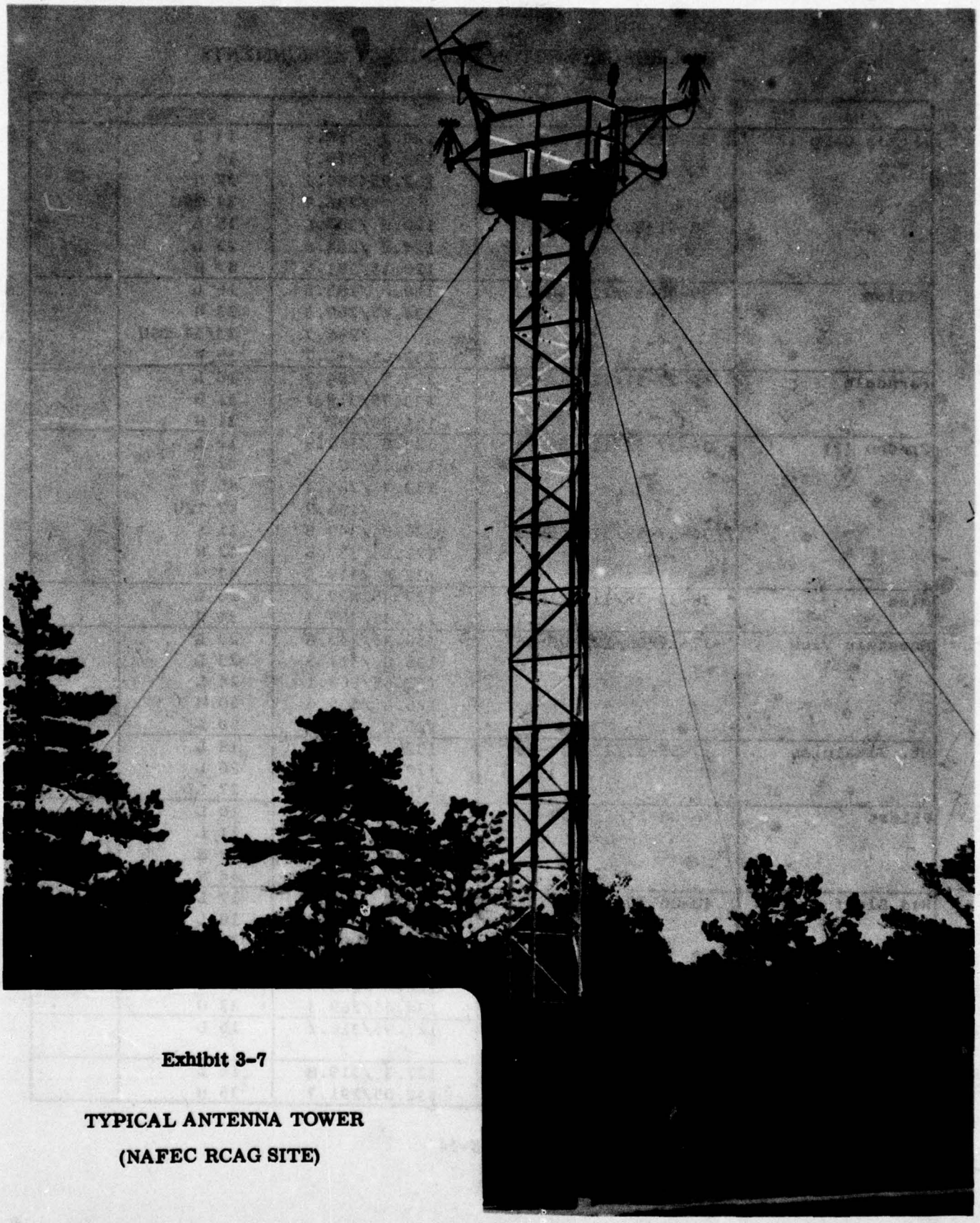


Exhibit 3-7

TYPICAL ANTENNA TOWER

(NAFEC RCAG SITE)

Exhibit 3-8

ZOA RCAGs: SECTOR FREQUENCY ASSIGNMENTS

NAME	LOCATION	V/U	SECTOR	d
Angels Camp (2)	38-01-14/120-35-02	120.2 /290.4	13 L	
		133.3 /319.9	14 L	
		132.95/269.1	32 H	
		/296.7	32 TSU	
	38-01-24/120-35/20	120.6 /307.8	15 L	
		124.2 /284.6	25 L	
		128.15/281.5	47 H	
Fallon	39-30-13/118-40-12	128.8 /285.5	16 L	
		134.45/269.3	33 H	
		/296.7	33/34 TSU	
		132.05/291.7	35 H	
Ferndale	40-29-51/124-17-37	123.9 /284.7	18 L	
		133.75/319.2	31 H	
		134.35/290.2	31 H	
Fresno (2)	36-37-51/119-56-04	123.8 /353.8	12 L	
		128.15/281.5	42 H	
		133.7 /285.4	45 H	
		/296.7	42 TSU	
	36-37-59/119-56-13	126.9 /343.8	11 L	
		128.55/357.6	42 H	
		132.8 /319.1	43 H	
Mina	38-33-55/118-01-55	127.45/327.8	16 L	
		132.45/307.3	34 H	
Mountain View	37-19-08/122-08-45	128.35/343.6	22 L	
		135.0 /317.5	23 L	
		132.65/263.1	24 L	
		126.8 /335.6	50 H	
		126.8 /335.6	50 L	
Mt. Tamalpias	37-55-37/122-37-40	132.2 /281.4	18 L	
		127.8 /353.5	26 L	
		121.2 /323.0	27 L	
Priest	36-08-14/120-39-58	128.7 /307.0	10 L	
		134.7 /387.0	11 L	
		132.8 /319.1	43 H	
		133.5 /290.5	44 H	
Red Bluff	40-06-20/122-14-06	120.4 /306.9	17 L	
		132.2 /281.4	18 L	
		134.35/290.5	31 H	
		132.95/269.1	32 H	
Reno	39-35-11/119-55-49	128.8 /285.5	16 L	
		134.45/269.3	33 H	
Sacramento	38-41-59/121-35-33	127.95/316.1	15 L	
* Shared with SAC RTR				
Tonopah	38-06-24/117-11-06	127.3 /319.8	16 L	
		132.05/291.7	35 H	

at Angels Camp two complete and independent radio facilities are sited several hundred yards apart.

If more channels are required at a radio facility with four channels already assigned, then four alternatives are available:

(1) add a fifth tower (limited by available real estate and separation criteria),

(2) add antennas to existing tower platforms (limited by antenna separation criteria and potential RFI),

(3) add a separate facility nearby (limited by available real estate), or

(4) employ antenna combining for multichannel operations (i.e., multicouplers).

For any appreciable degree of channel expansion required for colocation of facilities or to respond to increased air activity, the most feasible alternative is item (4).

The desirability of colocation of air/ground radio functions is attractive since there results a minimization of distinct and separate radio facilities. This approach offers the following advantages:

(1) A lowering of maintenance costs due to the reduction in number of radio facilities that have to be serviced.

(2) A reduction in number of radio equipments, because incorporating a 1 to 8 standby to primary equipment ratio favors a concentration of radio equipments. (See Phase I Final Report, FAA-RD-76-154, May 1977.)

(3) A reduction in number of leased remoting telephone circuits for the same reason as (2).

(4) A more cost-effective use of remote processing equipment utilized for automated maintenance functions.

Balanced against these advantages are the attendant problems of providing the required radio coverage with the minimum number of locations and operating an increased number of radio channels within the limited space of a given facility. The next chapter discusses some of the problems associated with both current air/ground operations and potential colocation approaches.

4

AIR/GROUND RADIO LIMITATIONS

4.1 RADIO COVERAGE

Radio coverage for the FAA air traffic control and flight services is provided by line-of-sight propagation within the VHF (118-136 MHz) and UHF (225-400 MHz) frequency bands. The required coverage, depending upon the operations supported, extends from ground level to over 45,000 feet. As discussed earlier, the air route ATC service is required over the en route airway structure and generally varies from 3,000 to 45,000 feet. Terminal area coverage for approach, departure, and runway operations extends from ground level (of the air terminal) to 20,000 feet with a maximum range of 60 nm as shown in Exhibit 3-1. The required radio coverage for flight services applies primarily to general aviation aircraft flying visual flight rules (VFR). The en route flight service coverage extends from MEA to 18,000 feet. The current disposition of flight service stations, usually located at airports, also provides radio coverage to ground level in the local vicinity of the airport.

While this report is primarily concerned with ATC en route radio facilities antenna systems, the concept of colocation of air/ground communication functions, as examined in the Phase I effort, requires consideration of combined coverage approaches. A so-called universal air/ground radio facility is one in which, through a modular building block concept, the facility can be engineered to provide the following at a single site:

(1) ATC coverage (high and low altitude en route),

(2) ATC coverage (terminal area),

(3) FSS coverage (en route and airport localized), and

(4) ATC redundant or augmented coverage.

The functions selected from this list, for a particular facility, depend upon its location as well as the coverage requirements that can be served from that location.

The radio coverage that is currently provided seldom approaches the ideal free space dipole pattern. Antenna patterns depart from the free space value because of terrain and man-made obstructions that create shadow areas of low signal; vertical lobing caused by direct and reflected signals; horizontal pattern distortion caused by antenna proximity effects and nonuniform vertical lobing structures in the horizontal plane; and insufficient signal power due to system losses.

Additionally, the antenna patterns for airborne antenna configurations are distorted from the ideal due to reflections from the aircraft surface and they also shift as a function of aircraft altitude relative to the ground based antenna.

Most of the antenna pattern difficulties (with the exception of obstacle shadowing) can be remedied by a sufficient increase in signal power that does not alter the pattern but extends the null areas to greater ranges. Unfortunately, the power radiated is limited (50 watts for high altitude en route operations) and, in many instances, further diminished by transmission line losses and various filter losses. One method for increasing signal power in a preferred area of airspace is to utilize a gain antenna. An omnidirectional gain antenna is usually limited to 3 to 6 db in gain due to the complexity of the required array. Directional gain antennas can provide 10 to 15 db of gain over a selected segment of coverage.

Directional antennas suffer two disadvantages that limit their general usefulness. First, their application is normally dedicated to the selected coverage direction, which inhibits their use as a shared antenna with a multicoupler servicing multiple radio channels. Second, such antennas are usually multi-element (i.e., with reflectors or directors or both), which limits their employment in severe environments.

The most practical approach to providing the required coverage within the fixed limitations hereinbefore examined is to exploit the maximum attainable antenna pattern

coverage by careful site, tower, and antenna system engineering; to minimize system loses where possible; and, finally, to fill in the remaining gaps with space diversity techniques. Space diversity is achieved by employing two or more radio facility locations in order to fill in coverage nulls by creating diverse line-of-sight look angles and propagation conditions. As might be expected, the majority of coverage difficulties exist at the lower altitudes.

A comprehensive study* performed for the Western Region by AWE-430 and AWE-437 shows that the current BUEC coverage for air traffic control sectors in the region falls short of providing full backup coverage. The primary conclusions were:

(1) ECAC charts disclose "holes" in 21 out of 85 air traffic (AT) sectors (25 percent) in the Western Region.

(2) The number of AT sectors that require coverage beyond the 90 percent reliability range (specified as 60 nm) of a BUEC or several BUECs are 69 out of 85 (80 percent).

Exhibit 4-1 illustrates a sample of the coverage analysis for the four Center Areas of Salt Lake City, Los Angeles, Oakland, and Albuquerque. Note that the coverage analysis is based upon line-of-sight theoretical considerations modified by terrain obstructions and does not include the additional effects of multipath, antenna pattern, distortion, and interference. The ECAC contours for the Red Bluff and Ukiah BUEC facilities are shown at the indicated altitudes for low altitude sector 42. The cross hatched area shows a hole in the Fortuna area along the air routes shown.

For Sector 42, the sector area covered by the two BUEC facilities is:

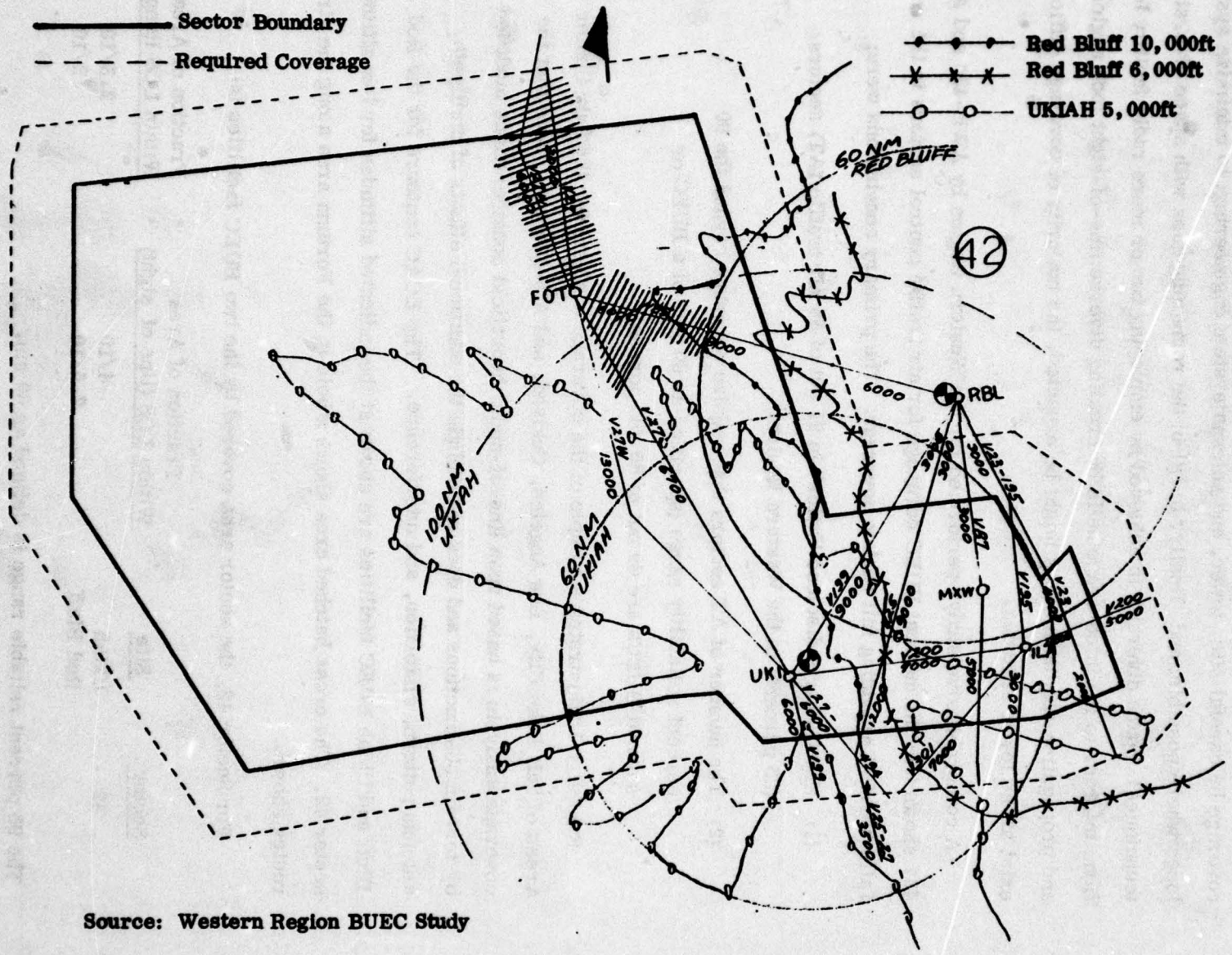
Sector	Site	Fraction of Area Within LOS (line of sight)	Fraction of Area Within LOS Range*
42	Ukiah	4/10	2.5/10
	Red Bluff	2.5/10	2/10

The 90 percent reliable range is defined as 60 nm.

*"FAA Western Region BUEC Coverage Study," May 1977.

Exhibit 4-1

RADIO COVERAGE: SECTOR 42



Source: Western Region BUEC Study

An augmentation of BUEC type radio coverage is to employ any available radio facility (except the primary coverage facilities) in the local area. This approach would include adjacent RCAGs, terminal area RTRs, and/or FSSs (RCO). Such an approach requires the placement of additional radio channels at existing facilities.

4.2 ANTENNA PATTERN DISTORTIONS

In addition to free space pattern distortion due to line-of-sight shielding by terrain and other obstacles, there are other forms of distortion, caused primarily by vertical lobing and horizontal pattern perturbations. Depending upon the radio frequencies employed, the proximity of antennas to tower and building structures, and to one another; the degree of distortion can be substantial.

It will be shown in Chapter 5 that the vertical lobing structure, as a function of antenna height and radio frequency, enhances the free space signal at VHF in the desired coverage areas, and degrades the free space signal at UHF with several nulls in the desired coverage areas.

In general, the number of lobes formed and their compression toward the horizon increases with frequency or with antenna height. These parameters are fixed for FAA operations; since the frequency allocations are established and the tower heights are invariable due to the necessity of clearing local terrain around the site. Several experiments employing a variable height portable tower at the NAFEC facility (see Chapter 7) were conducted and severe signal degradation was encountered with the lowered antenna.

Horizontal pattern distortion is difficult to quantify theoretically. A number of workers at Syracuse University have developed analytical techniques using the method of moments, which approximates conditions with integral equations that are solved by matrix inversion. (See for example, "Parasitic Effects," Warren and Adams, Syracuse University--IEEE Symposium on EMC, July 1970.)

The analysis treats simple dipoles isolated from the ground and clustered in various arrays--using one dipole as the driven element and the remaining dipoles as parasitic elements that reradiate the transmitted signal at an amplitude and phase dependent upon the length of the parasitic element and its separation from the driven element.

Exhibit 4-2 shows the expected radiation pattern for two half-wave length dipoles as a function of antenna separation. It can be seen that the depth of distortion varies from -12 db at 0.2λ, to about -1 db at 5.0λ. The addition of more parasitic elements will further modify this pattern since the resultant signal is the phasor sum of the contributing signals.

Several experiments were conducted at NAFEC to assess the degree of horizontal pattern distortion and the results are discussed in Chapter 5.

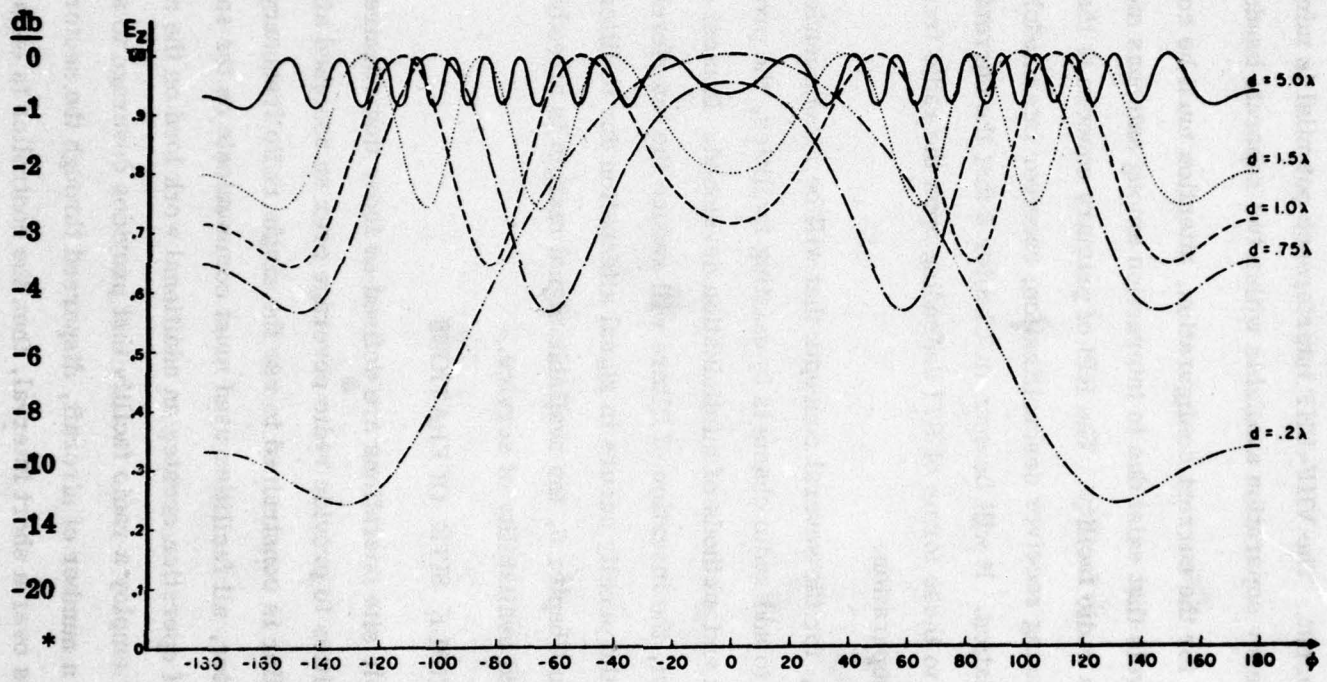
The theoretical treatment of horizontal pattern distortion does not allow for effects due to localized ground oriented structures such as tower platforms and antenna mounting hardware. Further, the distribution of terrain characteristics around a given radio site is almost never uniform so that the resulting vertical lobing structure will tilt as a function of azimuth. An extreme instance of this condition exists on mountain top sites where one side looks down into a plain area and the other side views a continuation of high altitude terrain. This siting is equivalent to an antenna mounted at an extreme height (thousands of feet) and also at a nominal height (50 feet). A very complex antenna pattern results, with a combination of a very fine grain lobing structure and a single major lobe--dependent upon azimuthal look angle.

4.3 RADIO FREQUENCY INTERFERENCE (RFI)

Multiple radio equipments (transmitters and receivers) operating within a bounded space will be susceptible to self-generated RFI. Careful attention to frequency management by limiting frequency assignments that are widely separated represents an effective solution. However, the requirements for radio frequency assignments (particularly at VHF) have accumulated to the point where the standard 500 kHz separation at VHF has been relaxed to as little as 200 kHz at some facilities. An alternate solution is to physically separate antennas so that the interfering signals are attenuated sufficiently through space loss. This solution is not practical at most en route facilities since the real estate available is normally limited to the boundary around the tower locations.

Exhibit 4-2

RADIATION PATTERN OF A HALF WAVE LENGTH DIPOLE IN THE PRESENCE OF A HALF WAVE LENGTH PARASITIC DIPOLE



Currently, the FAA operates a maximum of four radio channels (eight frequencies, four VHF and four UHF) at an en route facility. This allows the placement of a single channel (one VHF and one UHF) on a tower. For a single tower, the VHF transmitter and VHF receiver are on the same frequency so that the receiver is muted whenever the transmitter is keyed. The same situation applies to the UHF equipment. The VHF-UHF interference potential is minimized because of the wide frequency separation available within two separate bands.

Thus, for the current configuration, attention must be concentrated in the interference levels that exist due to interaction among antennas mounted on several towers at a radio facility. The RFI of primary concern is that due to transmitted signals causing receiver desensitization; receiver intermodulation; and transmitter intermodulation. It will be seen in Chapter 5 that the current facilities exhibit susceptibility to these forms of RFI depending upon the radio frequencies employed and their separation.

Since, for the several concepts that will be recommended in this report, it is necessary to add radio channels to existing facilities, the problem of RFI must be considered and methods of minimization developed. In most cases of the RFI encountered, the insertion of filters will reduce the interference to minimal levels. However, the penalty occurs in signal attenuation due to filter losses and, as will be shown in Chapter 5, the available signal margin is already insufficient to support the required availability of service.

4.4 MULTIPLE SITE OPERATIONS

Multiple site operations are defined as those that require the use of two or more radio facilities to provide radio coverage over an assigned airspace sector. Since the controller is constrained to use the single radio frequency (e.g., at VHF) assigned to that sector, all facilities used must communicate on the same frequency. This condition of operation creates an additional work load on the controller since he must selectively employ a radio facility that provides coverage to a specific aircraft in his sector. If a number of aircraft, dispersed through the sector, require communication transactions over a short interval, then the controller is engaged in a continual switching

operation. Multiple site operations are not the standard configuration, but occur frefrequently enough to require consideration. Additionally, it appears that the most feasible approach to providing a consistent (with the remaining elements of the air/ground radio system) service availability of the propagation path is to utilize space diversity involving multiple site operations.

A number of schemes have been explored by FAA that involve received signal comparison (from the multiple receivers). If the "best" received signal can be identified and isolated, then the transmitter associated with the receiver can be selected for ground to air communication. This involves a comparison of out-of-phase audio signals with a likely phase-time variance that makes relative assessment or addition of signals impractical. A further problem arises when aircraft may be flying along a seam between two coverage patterns so that received signals alternate between facilities.

The flexibility for utilizing multiple sites is a desirable asset for en route operations and is a requirement for FSS operations where the number of available frequencies is extremely limited. It appears that a substantial part of the problem can be solved through the use of automated selection made possible by interfacing with the NAS computer. Aircraft operation is stored in NAS for driving the controller's artificial display and these data can be employed for site selection. Further consideration of multiple site operations and their control is beyond the scope of the present effort and likely be examined as part of the FAA's RCS/RCCS program.

Part Two

ANALYSIS AND EVALUATION

5. Radio Antenna Configuration System Analysis

6. Alternative Antenna System Configuration Analysis

7. Experimental Evaluation

8. Antenna System Configurations for En Route Applications

9. Recommended Advanced R&D Program Air/Ground Radio

5

RADIO ANTENNA CONFIGURATION SYSTEM ANALYSIS

5.1 INTRODUCTION

The radio antennas employed for air/ground communications occupy a vital position in the overall system since they provide the interface between the radio equipment and the propagation medium. A consideration of antenna configurations must include a system analysis of the air/ground radio channel to determine the distribution of signal, noise, and interference.

This chapter presents an analysis of several of the major factors that influence system performance. The typical power budget, calculated on the basis of free space propagation, is affected by the vertical lobing of signals, horizontal pattern perturbations, radio frequency interference, and aircraft antenna characteristics. It is assumed that the ground antennas normally are represented by vertical dipoles, except for the circularly polarized swastikas used by FAA for VHF transmission of ground to air signals.

5.2 TYPICAL REPRESENTATION

For en route application of air/ground radio services, the FAA employs a cluster of four antennas mounted on one of four available towers at an RCAG facility. The four antennas on a single tower represent a single air/ground radio channel for air traffic control communications. The single radio channel utilizes two radio frequencies: one at VHF for civil air activity, and one at UHF for military air activity. The four antennas are required to support:

(1) radio transmitter operations at VHF,

(2) radio receiver operations at VHF,

(3) radio transmitter operations at UHF, and

(4) radio receiver operations at UHF.

Over the years of service, a number of antenna types have evolved and are in use, but, generally, the generic representations that are employed in a standard configuration are as follows (see Exhibit 5-1):

(1) VHF Transmit--Swastika omnidirectional, broad band, circularly polarized antenna
Gain = -4 dbi

(2) VHF Receive--Coaxial-omnidirectional, broad band, vertically polarized antenna
Gain = 0 dbi

(3) UHF Transmit--Discone-omnidirectional, broad band, vertically polarized antenna
Gain = -2 dbi

(4) UHF Receive--Discone (same as UHF Transmit)

Exhibit 5-2 shows a common tower arrangement of the above antennas, mounted for a single channel operation. The minimum distance between antennas is 8 feet.

Note that due to polarization loss the use of the swastika antenna entails a loss of approximately 3 db relative to a standard, vertically polarized dipole.

Since FAA antenna installations normally include a run of cable between equipment and antenna of over 100 feet, the potential cable loss is significant. The FAA employs RG-17U for most installations. Exhibit 5-3 shows a sampling of cable attenuation over the VHF and UHF bands.

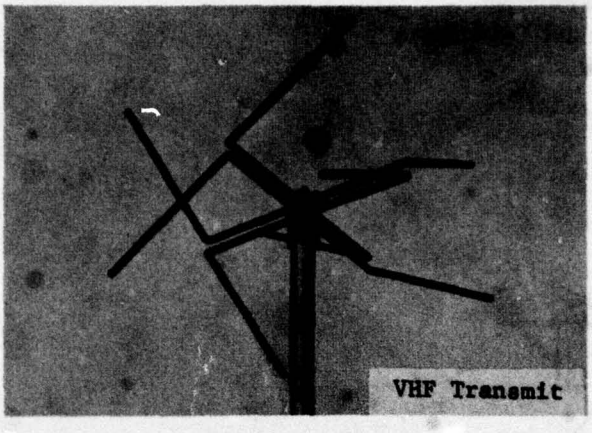
For purposes of this analysis, it is assumed that the current en route facilities are equipped with solid state transmitters and receivers:

(1) VHF/UHF Transmitter--GRT-21/GRT-22 (Exhibit 5-4)

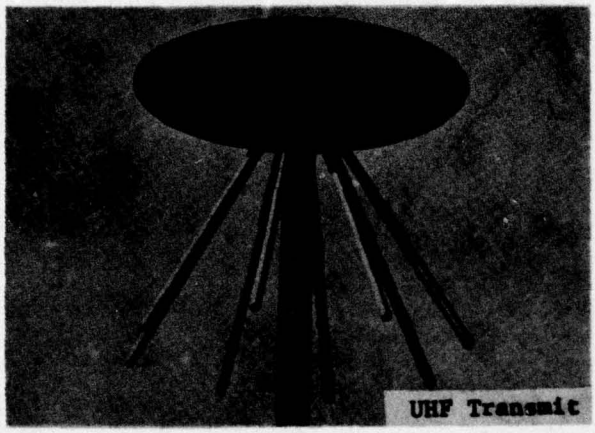
(2) VHF/UHF Receiver--GRR-23/GRR-24 (Exhibit 5-5)

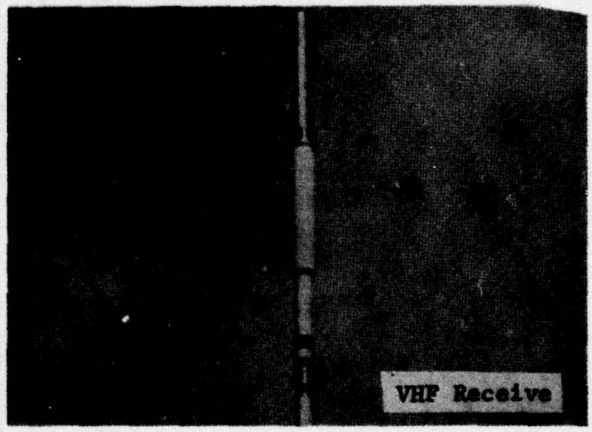
Exhibit 5-1

AVIATION ANTENNA


VHF Transmit


UHF Receive


UHF Transmit


VHF Receive

SPECIFICATIONS

MODEL	UHF Receive	UHF Transmit	VHF Transmit	VHF Receive
FREQUENCY RANGE	90-250 mHz	225-400 mHz	118-136 mHz	118-144 mHz
GAIN	1.5 db over isotropic	1.5 db over isotropic	1.5 db over isotropic	2 db over isotropic
VSWR	2:1 max.	2:1 max.	2:1 max..	3:1 max.
INPUT IMPEDANCE	50 ohms	50 ohms	50 ohms	50 ohms
POWER CAPABILITY	500 watts	1 kilowatt	200 watts	100 watts
CONNECTOR	type N	type N	type N	type N
ENVIRONMENTAL	120 mph wind no ice 70 mph wind ½ in. radial ice	150 mph wind no ice 120 mph wind ½ in. radial ice	100 mph wind ½ in. radial ice	100 mph wind ½ in. radial ice
MOUNTING	mate to 1½ in. IPS pipe	mate to 1¼ in. IPS pipe	mate to 2½ in. IPS pipe	mate to 1¼ in. IPS pipe
MATERIAL	aluminum	aluminum	aluminum	aluminum
NET WEIGHT	11 lbs.	4 lbs.	22 lbs.	5.25 lbs.
APPROX. SHIP WEIGHT	13 lbs.	5 lbs.	27 lbs.	9 lbs.
APPROX. SHIP VOLUME	1.5 cu. ft.	0.3 cu. ft.	18.7 cu. ft.	.67 cu. ft.
WIDTH	45.0 in.	18.0 in.	36.0 in.	3 in.
HEIGHT	41.5 in.	15.4 in.	21.0 in.	47 in.

Source: Antenna Products Division, DHY, Inc., Mineral Wells, Tx. Abridged Catalog (Airways Terminal Equipment Edition 1975), p. 9.

Exhibit 5-2

TOWER ARRANGEMENT
(Mounted for Single Channel Operation)

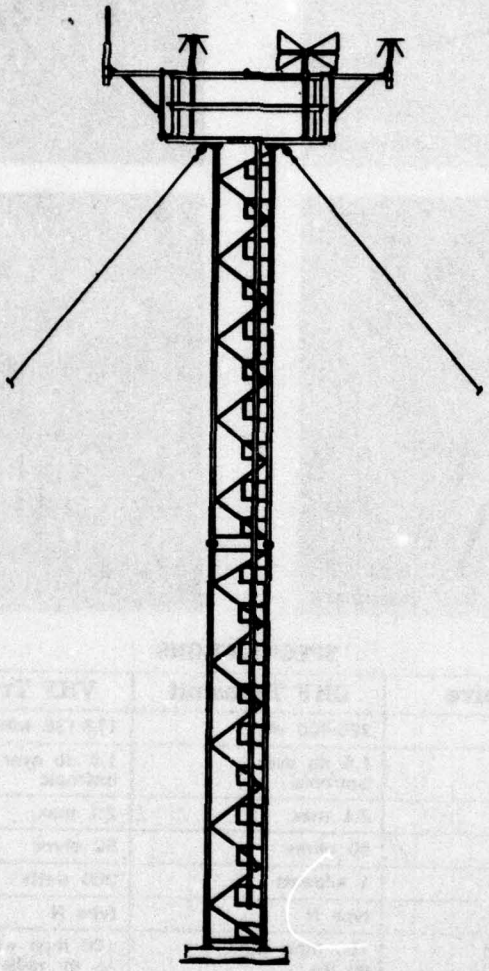


Exhibit 5-3

CABLE ATTENUATION

▼ START HERE TO SELECT BY TYPE NUMBER

▼ START HERE TO SELECT BY CHARACTERISTIC IMPEDANCE

ATTENUATION (dB/ 100 ft.) FREQUENCY IN MEGAHERTZ								VP %	RG CABLE TYPE
10	50	100	200	400	600	1000	3000		
.65	1.6	2.4	3.6	5.2	6.6	8.8	16.7	65.9	58 /U
.70	1.8	2.9	4.3	6.5	8.3	11.2	22	65.9	6A /U
.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	8 /U
.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	8A /U *
.45	1.26	2.3	3.4	5.2	6.5	9.0	17	65.9	9A /U *
.45	1.26	2.3	3.4	5.2	6.5	9.0	17	65.9	9B /U
.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	10A /U
.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	11 /U
.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	11A /U
.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	12A /U
.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	13A /U
.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	14A /U
.23	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	17A /U *
.23	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	18A /U *
.14	.42	.69	1.1	1.8	2.45	3.5	7.7	65.9	19A /U
.14	.42	.69	1.1	1.8	2.45	3.5	7.7	65.9	20A U
.29	.85	1.3	2.1	3.3	4.5	6.0	12.5	65.9	34B /U
.23	.61	.85	1.25	1.95	2.47	3.5	8.6	65.9	35B /U
1.3	3.2	4.8	7.0	10.5	13.0	17	32	65.9	55 /U
1.3	3.2	4.8	7.0	10.5	13.0	17	32	65.9	55A U
1.3	3.2	4.8	7.0	10.5	13.0	17	32	65.9	55B /U
1.4	3.5	5.3	8.3	11.5	17.8	20	40	65.9	58 /U
1.6	4.1	6.2	9.2	14.0	17.5	23.5	45	65.9	58A U
1.6	4.1	6.2	9.2	14.0	17.5	23.5	45	65.9	58C /U
1.1	2.7	4.0	5.7	8.5	10.8	14.0	26	65.9	59 /U
1.1	2.7	4.0	5.7	8.5	10.8	14.0	26	65.9	59B /U
.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	62 /U
.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	62A /U
.60	1.4	2.0	2.9	4.1	5.1	6.5	11.3	84	63B U
.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	71 U
.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	71A /U
.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	71B U
.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	74A /U
.60	1.4	2.0	2.9	4.1	5.1	6.5	11.3	84	79B U
.23	.61	.85	1.25	1.95	2.47	3.5	8.6	65.9	164 /U
—	—	—	—	2.0	—	—	—	65.9	174 U
.23	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	177 /U
.65	1.6	2.4	3.6	5.2	6.6	8.8	16.7	65.9	212 U
.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	213 U *
.45	1.26	2.3	3.4	5.2	6.5	9.0	17	65.9	214 /U *
.56	1.35	2.1	3.1	5.0	6.5	8.8	16.7	65.9	215 /U
.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	216 U
.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	217 /U
.225	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	218 U
.225	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	219 /U
.17	—	.69	1.12	1.85	—	3.6	7.7	—	220 /U
.17	—	.69	1.12	1.85	—	3.6	7.7	—	221 /U
1.3	3.2	4.8	7.0	10.5	13.0	17.0	32	65.9	223 U
.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	224 U

SC—silver plated copper, C—bare copper, PE—polyethylene, NCV—non-contaminating vinyl, V—polyvinylchloride, TC—tinned copper, CW—copperweld

* Cable types currently used by FAA

Ohms Code: ^ Through to 55 □ 56 Through 80 ^ 81 Through 100 ° 101 Through 200

(Reprinted from Special Report on Electronics. Copyright by U.S. Industrial Publications, Inc. 209 Dunn Avenue, Stamford, Connecticut.)

Exhibit 5-4

VHF/UHF TRANSMITTER CHARACTERISTICS

VHF/UHF TRANSMITTER

VHF MODEL NO. 3201
UHF MODEL NO. 3202
VHF MODEL NO. 3211
UHF MODEL NO. 3212

Frequency Range UHF: 225.00—399.95 MHz
VHF: 116.00—149.975 MHz

Channels UHF: 3500 (50 KHz) Optional: 7000 (25 KHz)
VHF: 680 (50 KHz) Optional: 1360 (25 KHz)

Stability .001%
R. F. Power Output
Solid-State Exciter VHF Model No. 3201 10 Watts Carrier Minimum
UHF Model No. 3202 10 Watts Carrier Minimum
Linear Amplifier VHF Model No. 3211 50 Watts Carrier Minimum
UHF Model No. 3212 50 Watts Minimum

Carrier Noise 45 db below 90% Mod.
Harmonic and Spurious Outputs 80 db below Carrier
Intermodulation 40 db below for 20 db coupling at $\Delta f = .5$ MHz VHF, 1 MHz UHF
Modulation Capability 90% A.M., −35 to + 10 dbm Input
Distortion 10% Max. @ 90% Modulation
Audio Frequency Range .3—6 KHz and .3—25 KHz (for wide bandwidth data)
Primary Power 105/120, 210/240 VAC ±10% (47—420 Hz), 22—30 VDC

Operational Temperature Range −29°C to +60°C
Storage Temperature Range −62°C to +71°C
Applicable Military Specs MIL-E-4158C
MIL-STD-454
MIL-Q-9858
MIL-STD-461

Size
Solid-State Exciter 5¼" x 19" x 16⅝" (13.4 x 48.5 x 42.5 cm)
Linear Amplifier 7" x 19" x 18⅜" (18.0 x 48.5 x 47.0 cm)
Weight
Solid-State Exciter 45 pounds (20.0 Kg)
Linear Amplifier 75 pounds (35.0 Kg)
MTBF 10,000 Hours (Excluding Linear Amplifier Electron Tube)
Mean Repair Time 15 Minutes

FEATURES

Audio Compression and Limiting to limit crosstalk and overmodulation.
Fault Isolation to module level from front panel.
Ball-bearing slides.
Channel re-alignment controls available at the front panel.
Modular construction.
Easy UHF to VHF conversion.
All Solid-State Exciter.
Automatic High VSWR Protection.
Automatic Linear Amplifier Fault Detection.

KEYING MODES

Carbon and Dynamic Microphones.
Optional Keying by Current Voltage or Tone.

AEROSPACE/OPTICAL DIVISION
DEFENSE-SPACE GROUP
ELECTRO-OPTICAL OPERATIONS
3700 E PONTIAC ST., FORT WAYNE, IND. 46803
ITT

Exhibit 5-5

VHF/UHF TRANSMITTER CHARACTERISTICS

VHF/UHF RECEIVER

Frequency Range Model No. 3101 VHF: 116.00—149.95 MHz
Model No. 3102 UHF: 225.00—399.95 MHz

Channels UHF: 3500 (50 KHz) Optional: 7000 (25 KHz)
VHF: 680 (50 KHz) Optional: 1360 (25 KHz)

Stability ±.001%
Sensitivity 10 db S + N/N @ 3 μv, 30% Mod.
Audio Frequency Range .3—3 KHz

Audio Output (2) 100 mw (adjustable) (600 ohms)
Audio Hum and Noise 50 db below 100 mw
Harmonic Distortion 10% Maximum @ 30% Mod.
20% Maximum @ 90% Mod.

AGC Range ±3 db (6 μv to 1 v)
Image Rejection 80 db Minimum
Spurious Response 80 db Minimum
Intermodulation 76 db (Δf = 500 KHz VHF, 2 MHz UHF)
Cross-Modulation 100 db (±.5 MHz VHF, ±1.5 UHF)
Desensitization less than 2 db for —10 dbm interfering signal
±.5 MHz VHF, ±1.5 MHz UHF
Selectivity ±18 KHz (6 db) 50 KHz Channel Spacing
± 9 KHz (6 db) 25 KHz Channel Spacing

Squelch Adjustable 3—50 μv
Primary Power 105/210, 120/240 VAC ±10% (47—420 Hz),
22—30 VDC
Power Input Less than 30 W
Operational Temperature Range —29°C to +60°C
Storage Temperature Range —62°C to +71°C
Applicable MIL Specs MIL-E-4158C
MIL-STD-454
MIL-Q-9858
MIL-STD-461

Weight 22 pounds (10 Kg)
Size 3½" x 19" x 12" (8.9 x 48.5 x 30.5 cm)
MTBF 10,000 Hours (demonstrated)

Mean Time to Repair 15 Minutes

FEATURES

- Audio Compression eliminates crosstalk.
- Channel re-alignment controls available at front panel.
- Fault isolation to module level at front panel.
- Ball-bearing slides.
- Modular construction.
- Easy UHF to VHF conversion.
- All Solid-State.
- Built-in Automatic Battery Charger.
- Auxiliary IF Output.
- Impulse Noise Blanking.
- 25 KHz Wideband Data Output.

AEROSPACE/OPTICAL DIVISION
DEFENSE-SPACE GROUP
ELECTRO-OPTICAL OPERATIONS
3700 E PONTIAC ST., FORT WAYNE, IND. 46803
ITT

For en route operations, which are divided into high altitude sectors (HAT) and low altitude sectors (LAT), FAA employs two levels of RF power output:

(1) HAT operations--50 watts per carrier

(2) LAT operations--10 watts per carrier (only the exciter section of GRT 21/22 is used)

The altitude boundary between the sectors is placed at 18,000 feet.

The FAA provides air traffic control services to three classes of user aircraft: air carrier, general aviation, and military. The airborne radio transceivers used occupy a wide range of capability and performance. For purposes of analysis, it is assumed that the following transmitter powers apply:

(1) Air Carrier--25 watts (+44 dbm)

(2) General aviation--10 watts (+40 dbm)

(3) Military--25 watts (+44 dbm)

5.3 POWER BUDGET

Power budgets for nominal mid band frequencies are calculated for both VHF and UHF for high and low altitude sectors of the maximum range of expected operations. To develop information about radio signal margin (i.e., excess available signal), the estimated receiver noise figures and system noise power (both referred to the receiver input) were derived. The receiver noise figure calculations are shown in Exhibit 5-6. The system noise power calculations are shown in Exhibit 5-7.

The power budget calculation for VHF is shown in Exhibit 5-8. The power budget derived is based on free space loss without consideration of additional losses due to lobing or horizontal pattern distortion.

Note that for the losses shown, the VHF radio channel appears to operate with a small positive signal margin for high and low altitude sectors for both the downlink and uplink paths.

Exhibit 5-6

RECEIVER NOISE FIGURES

A--Ground Receiver:

Sensitivity--3 μV (50 ohms); $\frac{S+N}{N}$ = 10 db; $\frac{S}{N}$ = 9.5 db

Signal Power (in) = $\frac{E^2}{4R}$ = -103.4 dbm

Noise Power (in) = KT_oB = -128.4 dbm (B=36 kHz; T_o = 290° K)

$\frac{S}{N}$ (in) = 128.4 -103.4 = 25 db

For AM-DSB Detection

$\left(\frac{S}{N}\right)_i = \frac{1}{m^2} \left(\frac{S}{N}\right)_o$ m = 30% modulation

$\left(\frac{S}{N}\right)_i$ + 10.5 db = $\left(\frac{S}{N}\right)_o$; Detection Loss (D) = 10.5 db

Signal/Noise Gain (G) with Post Detection Filtering

$$G = \frac{\text{IF Bandwidth}}{\text{AF Bandwidth}} = \frac{36.0}{5.4} = 8.2 \text{ db}$$

Noise Figure F_R (Ground) = $\frac{S}{N}$ (in) -D + G - $\frac{S}{N}$ (out)

F_R (Ground) = 25 -10.5 + 8.2 - 9.5

F_R (Ground) = 13.2 db

B--Airborne Receiver:

Sensitivity -- 3 uV (50 ohms); $\frac{S+N}{N}$ = 10 db

Noise Figure F_R (Airborne) = 25 - 10.5 + 8.2 - 4.8 db

F_R (Airborne) = 17.9 db

Exhibit 5-7

SYSTEM NOISE REFERRED TO RECEIVER INPUT



System Noise Temperature: T_s

$$T_s = \frac{T_A}{L_1} + T_o \left(1 - \frac{1}{L_1}\right) + T_o (F_R - 1)$$

Antenna Temperature

$$T_A \text{ (Ground)} = \frac{15 \text{ db}}{K T_o B} = 9170^\circ \text{ K}$$

$$T_A \text{ (Airborne)} = \frac{0 \text{ db}}{K T_o B} = 290^\circ \text{ K}$$

Cable Loss

L_1 (Ground) = 2 db (1.58)

L_1 (Airborne) = 1 db (1.26)

T_s (Ground) = 5803 + 106 + 5768 = 11677°K

T_s (Airborne) = 236 + 60 + 17591 + 17881°K

System Noise at Receiver Input

N_s (Ground) = K T_s (Ground) B = $1.38 \times 10^{-23} \times 11677 \times 36 \times 10^3$

N_s (Ground) = - 112.4

N_s (Airborne) = K T_s (Airborne) B = $1.38 \times 10^{-23} \times 17881 \times 36 \times 10^3$

N_s (Airborne) = - 110.5 dbm.

Exhibit 5-8

POWER BUDGET
(VHF: f = 127 MHz)

Downlink	HAT (150 mi)	LAT (60 mi)
A/C Power (25 watts)	44 dbm	44 dbm
Cable Loss	- 1 db	- 1 db
A/C Antenna Gain	- 2 db	- 2 db
Space Loss	-122 db	-114 db
Gnd. Antenna Gain	0 db	0 db
Cable Loss	- 2 db	- 2 db
Available Signal	-83 dbm	-75 dbm
Signal/Noise	30 db	38 db
Signal Margin (over 25 db)	5 db	13 db
Signal Margin (A/C Power = 10 watts)	1 db	9 db

Uplink	HAT (150 mi)	LAT (60 mi)
Gnd. Tx. Power	47 dbm	40 dbm
Cable Loss	- 2 db	- 2 db
Gnd. Antenna Gain (Swastika)	- 2 db	- 2 db
Polarization Loss	- 3 db	- 3 db
Space Loss	-122 db	-114 db
A/C Antenna Gain	- 2 db	- 2 db
Cable Loss	- 1 db	- 1 db
Available Signal	-85 dbm	-84 dbm
Signal/Noise	25.5 db	26.5 db
Signal Margin (over 25 db)	.5 db	1.5 db

The UHF power budget calculation is shown in Exhibit 5-9. Due to the increased free space loss at higher frequencies, the UHF propagation path shows negative signal margins for both downlink and uplink paths for the high altitude sectors. The uplink low altitude path also shows a signal deficit. These power budgets will be further modified on the basis of additional signal loss factors considered later in this chapter. The significant result is that either modest positive signal margins or definite negative signal margins occur, without factoring in the losses due to signal fading, vertical lobing, horizontal pattern distortion, and aircraft antenna system characteristics. The following sections will consider the the effect of those additional factors as well as signal deterioration due to radio frequency interference.

5.4 VERTICAL LOBING

An antenna located in proximity to the earth's surface does not exhibit a free space pattern for radiation. Energy directed toward the earth is reflected and combines with the free space energy to produce an interference pattern. When the path length difference between the direct and reflected ray (for a two-path propagation model) is any multiple of wave lengths, a reinforcement of the in-phase signals results. Destructive interference occurs when the signals arrive out of phase. The degree of reinforcement or cancellation depends upon the reflection coefficient of the surface. The reflection coefficient for vertically polarized waves is always less than that for horizontally polarized waves so that the excursion of the resultant signal about the free space value is correspondingly less for vertically polarized waves. Since vertical polarization provides a more stable signal environment, it is normally employed for air/ground radio communication. The loci of points for both signal reinforcement and signal cancellation form a family of hyperbolas with the following equation (from Reed and Russell, Ultra High Frequency Propagation, 1965):

$$\frac{h_2^2}{a^2} + \frac{d^2}{b^2} = 1$$

Where

$$a^2 = \left(\frac{\theta\,\lambda}{4\,\pi}\right)^2; \quad b^2 = h_1^2 - \left(\frac{\theta\,\lambda}{4\,\pi}\right)^2$$

Exhibit 5-9

POWER BUDGET
(UHF: f = 315 MHz)

Downlink	HAT (150 mi)	LAT (60 mi)
A/C Power (25 watts)	44 dbm	44 dbm
Cable Loss	- 1.5 db	- 1.5 db
A/C Antenna Gain	- 2 db	- 2 db
Space Loss	-130 db	-122 db
Gnd. Antenna Gain	0 db	0 db
Cable Loss	- 3 db	- 3 db
Available Signal	- 92.5 dbm	- 84.5 dbm
Signal/Noise	19.9 db	27.9 db
Signal Margin (over 25 db)	- 5.1 db	2.9 db
Signal Margin (A/C Power = 10 watts)	- 9.1 db	- 1.1 db

Uplink	HAT (150 mi)	LAT (60 mi)
Gnd. Tx. Power	47 dbm	40 dbm
Cable Loss	- 3 db	- 3 db
Gnd. Antenna Gain (Discone)	0 db	0 db
Space Loss	-130 db	-122 db
A/C Antenna Gain	- 2 db	- 2 db
Cable Loss	- 1.5 db	- 1.5 db
Available Signal	- 89.5 dbm	- 88.5 dbm
Signal/Noise	21.0 db	22.0 db
Signal Margin (over 25 db)	- 4.0 db	- 3.0 db

h_1 = height of transmitting antenna

h_2 = height of receiving antenna

d = horizontal separation between antennas

λ = wave length of the transmitted wave

θ = path length difference in radians

The interaction of signals forms a lobe structure in the vertical plane with maxima and minima determined by the amount of reinforcement and cancellation. The number of lobes formed in the 90-degree quadrant between the horizon (0 degrees) and overhead (90 degrees vertical) is a function of the wavelength and the height of the transmitting antennas. The number of lobes for any wavelength, λ, and antenna height h_1 can be determined by setting:

$$b^2 = h_1^2 - \left(\frac{\theta\lambda}{4\pi}\right)^2 = 0$$

For example, if $h_1 = 2\lambda$ then $2\lambda = \left(\frac{\theta\lambda}{4\pi}\right)$ or $\theta = 8\pi$

The result, $\theta = 8\pi$ or 1440°, represents the maximum occurring at the 90-degree vertical and is 4 x 2π or the fourth lobe in the quadrant. Thus for $h_1 = 2\lambda$ there are 4 lobes formed in the antenna pattern. In general, the number of lobes formed is equal to the antenna height expressed as the number of half wavelengths. It is, therefore, important to employ antenna heights consistent with a small number of lobes. As the antenna height or the radio frequency is increased, the number of vertical lobes is also increased with the additional lobes forming at the zenith and compressing those at lower elevation angles. The distribution of lobes over the quadrant is not uniform.

Sample calculations were carried out using a two path propagation model (Exhibit 5-10) in order to estimate the lobing structure at VHF and UHF for antenna heights of 55 feet which is typical of FAA practice (also see Appendix A). The parameter of interest is the resultant field due to the direct and reflected rays. The ratio of the resultant field to the free space field can be calculated as shown in Exhibit 5-11. A sample calculation is shown for specific parameters of distance and height for a frequency of 127 MHz. Exhibit 5-12 shows the signal power gain relative to the free

Exhibit 5-10

TWO PATH PROPAGATION GEOMETRY FOR CALCULATION OF EARTH GAIN FACTORS

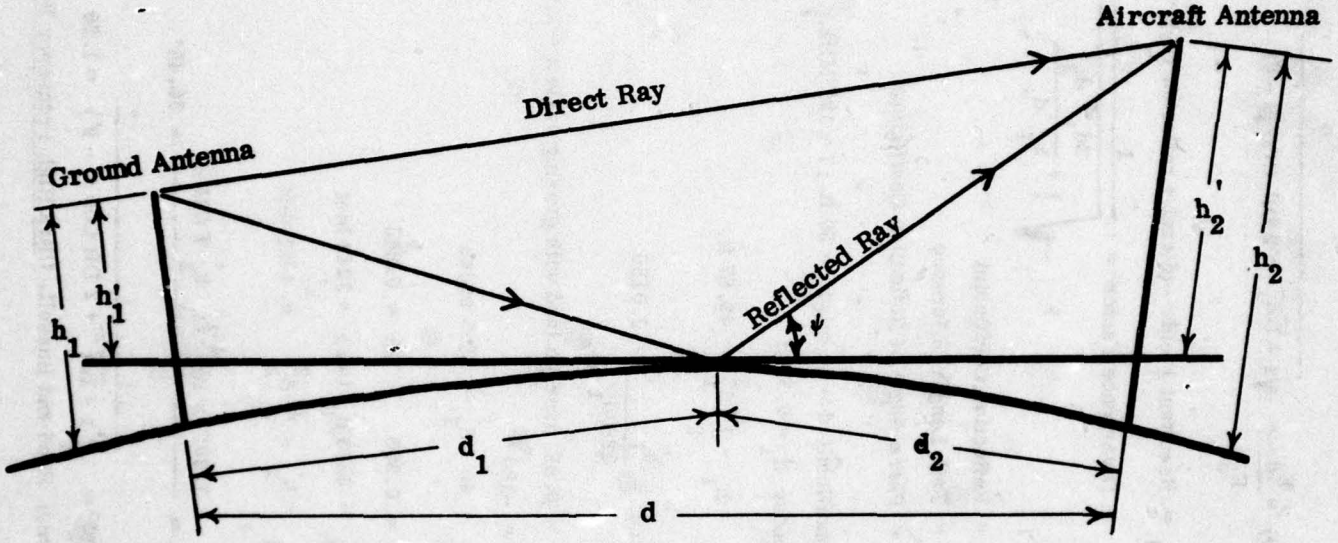


Exhibit 5-11

CALCULATION OF EARTH GAIN FACTOR: g(θ)

$$g(\theta) = \frac{E_d}{E_o} = \sqrt{1 + \overline{DR}^2 + 2\,DR\,\cos(\theta - \phi)}$$

E_d = Resultant Field -(direct + reflected rays)

D = Divergence Factor = $\dfrac{1}{\sqrt{1 + \dfrac{2d_1^2\, d_2}{h_1'\, d}}}$

R = Reflection Coefficient

θ = Path Length Difference

ϕ = Phase Angle of Reflection Coefficient

* * *

Conditions: d = 40 mi; h_1 = 50 ft.; f = 127 MHz.

Choose d_1 = 0.5 mi

$h_1' = h_1 - \frac{1}{2} d_1^2 = 49.87$ ft.

$\tan\psi = \dfrac{h_1'}{5280 d_1} = 0.0189$

R = 0.85 average land with grazing angle x = 1.0

$\phi = -180°$

$d_2 = 40 - d_1 = 39.5$ miles

D = 0.995 DR = 0.845

$h_2' = 5280\, d_2 \tan x = 3942$ feet

$h_2 = h_2' + \frac{1}{2} d_2^2 = 4721$ feet

$$\theta = \frac{1.385 \times 10^{-4}\, h_1'\, h_2'\, f(\text{MHz})}{d} = 86.45° \qquad \theta - \phi = 266°$$

$$g(\theta) = \sqrt{1 + \overline{DR}^2 + 2\,DR\,\cos(\theta - \phi)} = 1.26$$

Source: Reed and Russell. Ultra High Frequency Propagation.

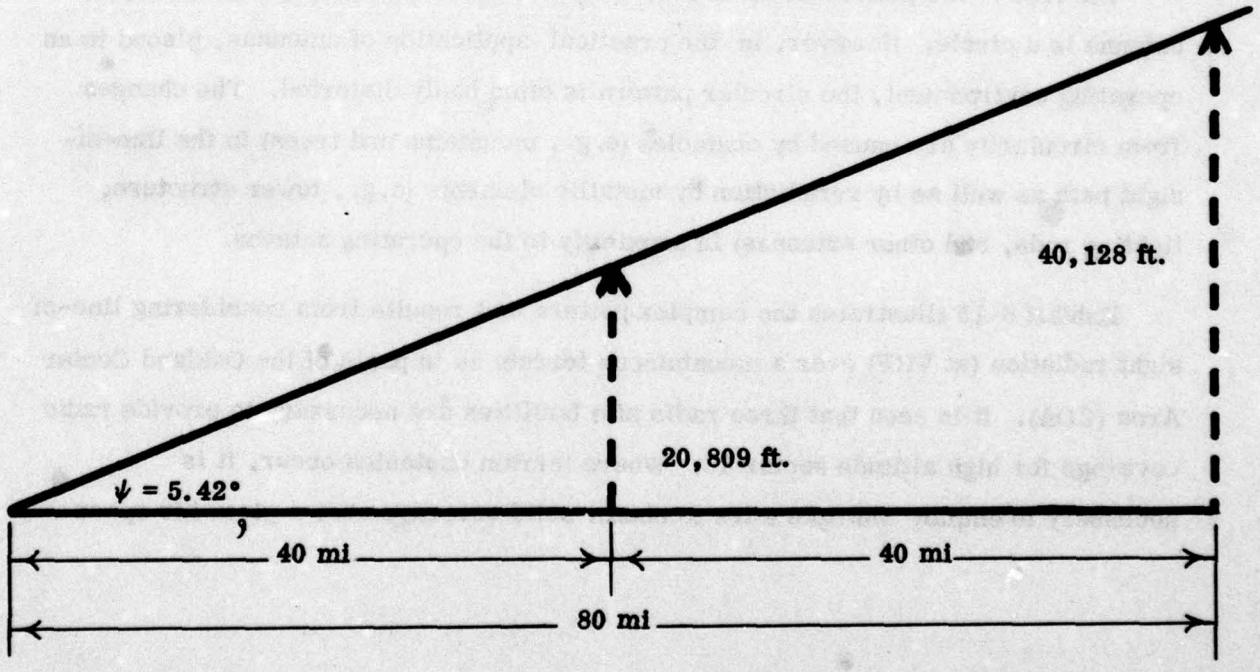
Exhibit 5-12

SIGNAL POWER GAIN AS A FUNCTION OF ALTITUDE

d = 40 miles f=127 MHz

d_1 Miles	h_2 Feet	$g(\theta)$	$g(\theta)^2$	Gain (db)*	ψ (degrees)
0.5	4,221	1.26	1.60	2.0	1.08
0.4	5,718	1.50	2.25	3.5	1.35
0.3	7,390	1.69	2.85	4.5	1.80
0.2	10,732	1.60	2.56	4.1	2.71
0.1	20,809	1.04	1.08	0.3	5.42

*Relative to free space



(not to scale)

space value for a range of aircraft altitudes from 4,000 to 20,000 feet. As shown in Exhibit 5-12, the 80 mile range at the same grazing angle of 5.42 degrees covers altitudes to 40,000 feet that would include the service volume in both LAT and HAT sectors. Exhibit 5-12 also shows that signal reinforcement occurs throughout the range of altitudes shown and the gain varies from 0.3 to 4.5 db over the free space value.

At UHF, there are more lobes so that minima occur through the range of altitudes shown in Exhibit 5-13. Power levels as large as 13 db below the free space value occur within the airspace shown. Since antenna heights need to clear the surrounding terrain, it may not be practical to reduce the height of the UHF antennas in order to reduce the number of lobes. Exhibit 5-14 shows the optimum antenna heights for VHF and UHF frequencies to obtain solid radio coverage over the altitudes and ranges of interest.

In summary, vertical lobing (see appendix) does not appear to adversely affect signal levels within the VHF band; however, at UHF frequencies with antenna heights of 55 feet there are signal nulls with depths of about 13 db below the free space level.

5.5 HORIZONTAL PATTERN DISTORTION

The free space pattern in the horizontal plane for a vertically polarized dipole antenna is a circle. However, in the practical application of antennas, placed in an operating environment, the circular pattern is often badly distorted. The changes from circularity are caused by obstacles (e.g., mountains and trees) in the line-of-sight path as well as by reradiation by metallic elements (e.g., tower structure, lighting rods, and other antennas) in proximity to the operating antenna.

Exhibit 5-15 illustrates the complex pattern that results from considering line-of sight radiation (at VHF) over a mountainous terrain as in parts of the Oakland Center Area (ZOA). It is seen that three radio site facilities are necessary to provide radio coverage for high altitude sector 16. Where terrain obstacles occur, it is necessary to employ multiple sites to obtain solid coverage over a given air space

Exhibit 5-13

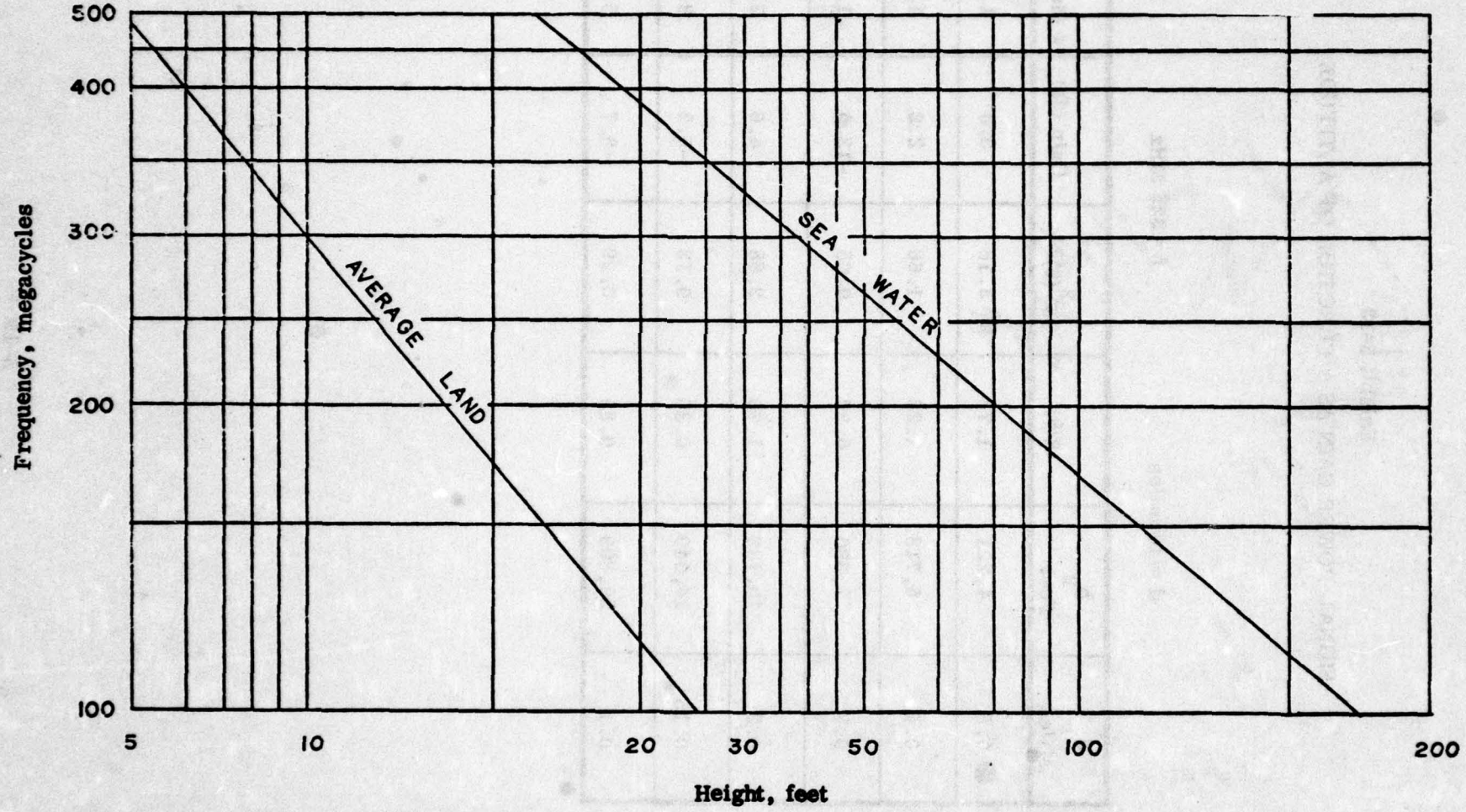
SIGNAL POWER GAIN AS A FUNCTION OF ALTITUDE

d = 40 miles f = 325 MHz

d_1 Miles	h_2 Feet	$g(\theta)$	$g^2(\theta)$	Gain (db)	ψ (degrees)
0.5	4,221	1.78	3.18	5.0	1.08
0.4	5,718	1.29	1.66	2.2	1.35
0.3	7,390	0.22	0.05	-13.0	1.80
0.2	10,732	1.70	2.88	4.6	2.71
0.15	14,049	0.36	0.13	-5.2	3.60
0.1	20,809	0.55	0.29	-8.7	5.42

Exhibit 5-14

OPTIMUM ANTENNA HEIGHTS FOR MAXIMUM SOLID COVERAGE RANGES



Source: Reed and Russell, Ultra High Frequency Propagation.

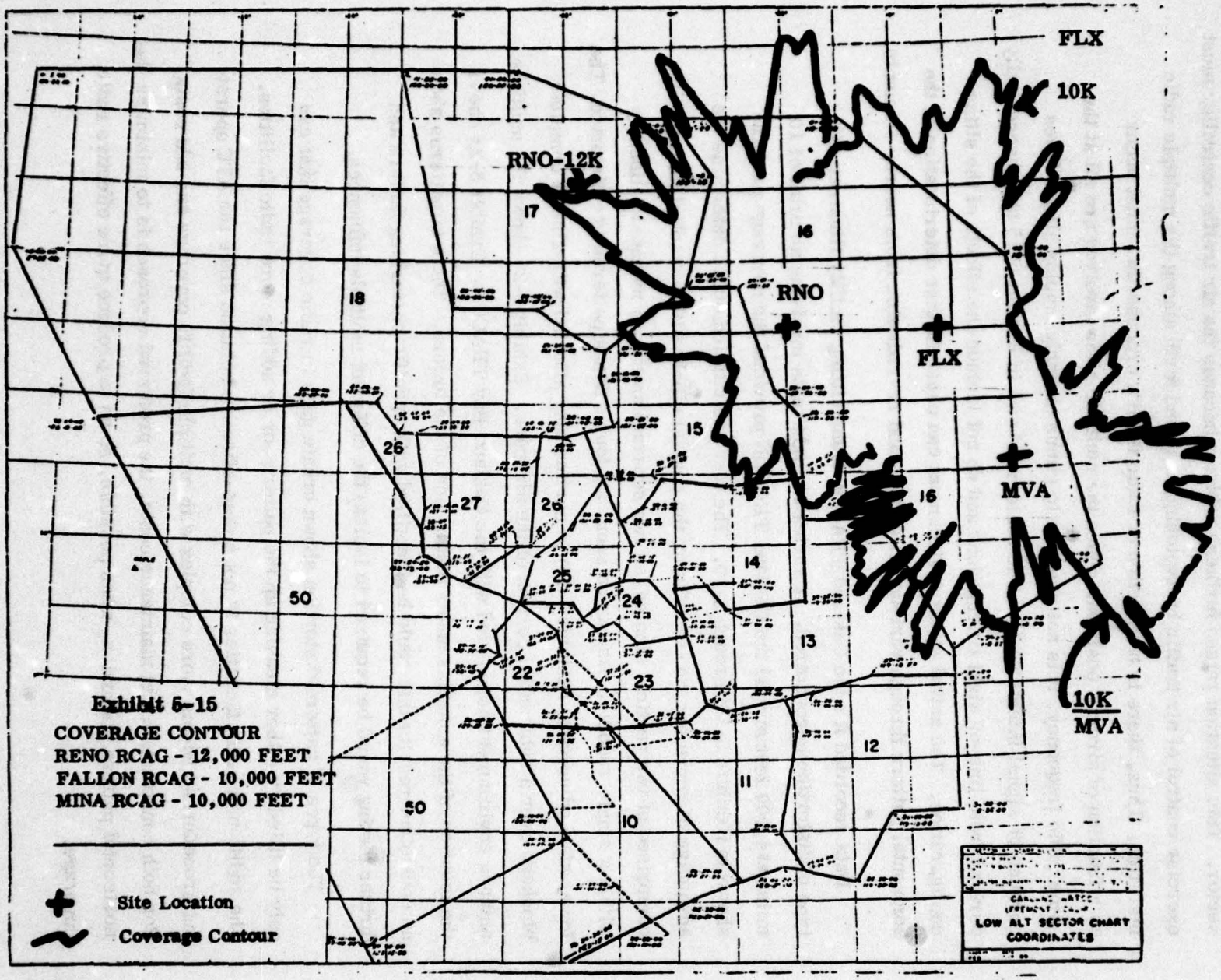


Exhibit 5-15

COVERAGE CONTOUR
RENO RCAG - 12,000 FEET
FALLON RCAG - 10,000 FEET
MINA RCAG - 10,000 FEET

sector. This situation raises further problems because the air traffic controller must exercise control of air traffic by switching back and forth among the multiple radio facilities. Thus, there is a selection of radio facility process that must occur as a function of aircraft position. Since the multiple sites involved are all at the same radio frequency, it is not possible to simultaneously employ all facilities because of signal interference. The contours shown in Exhibit 5-15 are theoretically derived from line-of-sight calculations and do not include the effects of the siting configuration. The actual siting environment can cause further deterioration of the horizontal pattern through various reflections and re-radiation from nearby elements.

Data recorded for the Oakland TRACON transmitting facility illustrate the type of distortion encountered. A series of flight tests involving an orbit of 10 miles at 4,000 feet around the Oakland TRACON provided the coverage patterns shown in Exhibits 5-16 through 5-19. The test was carried out to determine the advantage of replacing the swastika or the coaxial dipole with a stacked antenna comprised of two vertical dipoles (as two separate antennas) mounted colinearly within a single radome. As can be seen, all four antenna patterns are distorted. The lower stacked vertical (Exhibit 5-18) is particularly affected with almost complete blockage over a substantial portion of the airspace. Exhibit 5-20 shows the multiple antenna environment associated with the Oakland Bay TRACON. Exhibit 5-21 shows the location of the antennas under test on one of the towers. The test patterns show no consistent results that could be identified with specific perturbing factors and further testing would be required to isolate the different multiple influences.

The types of pattern distortion shown create gaps in radio coverage that can only be filled by either cleaning up the patterns or by adding more radio facilities. The addition of radio facilities is not a cost-effective solution since the ATC operating procedures become more complex with multiple facility coverage and add costs. For both construction and maintance costs, the preferred approach is to minimize the horizontal pattern distortion, when possible, so as to produce more effective radio coverage.

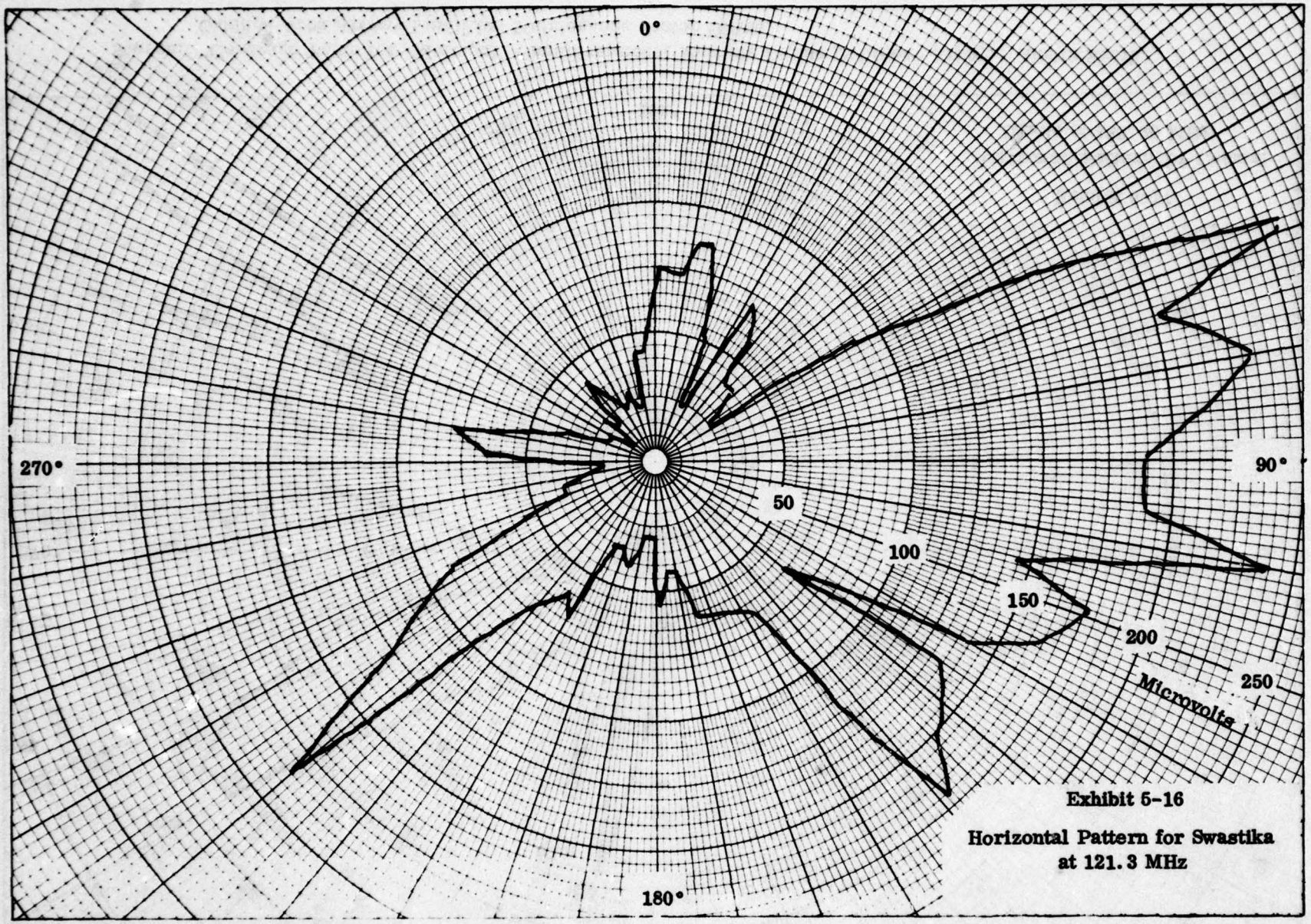


Exhibit 5-16

Horizontal Pattern for Swastika at 121.3 MHz

Source: "Coverage Tests for 'Muldipol' Omnidirectional Multiple Dipole Collinear Array," Austin Smith, Oakland Area Airway Facilities Maintenance Sector Office.

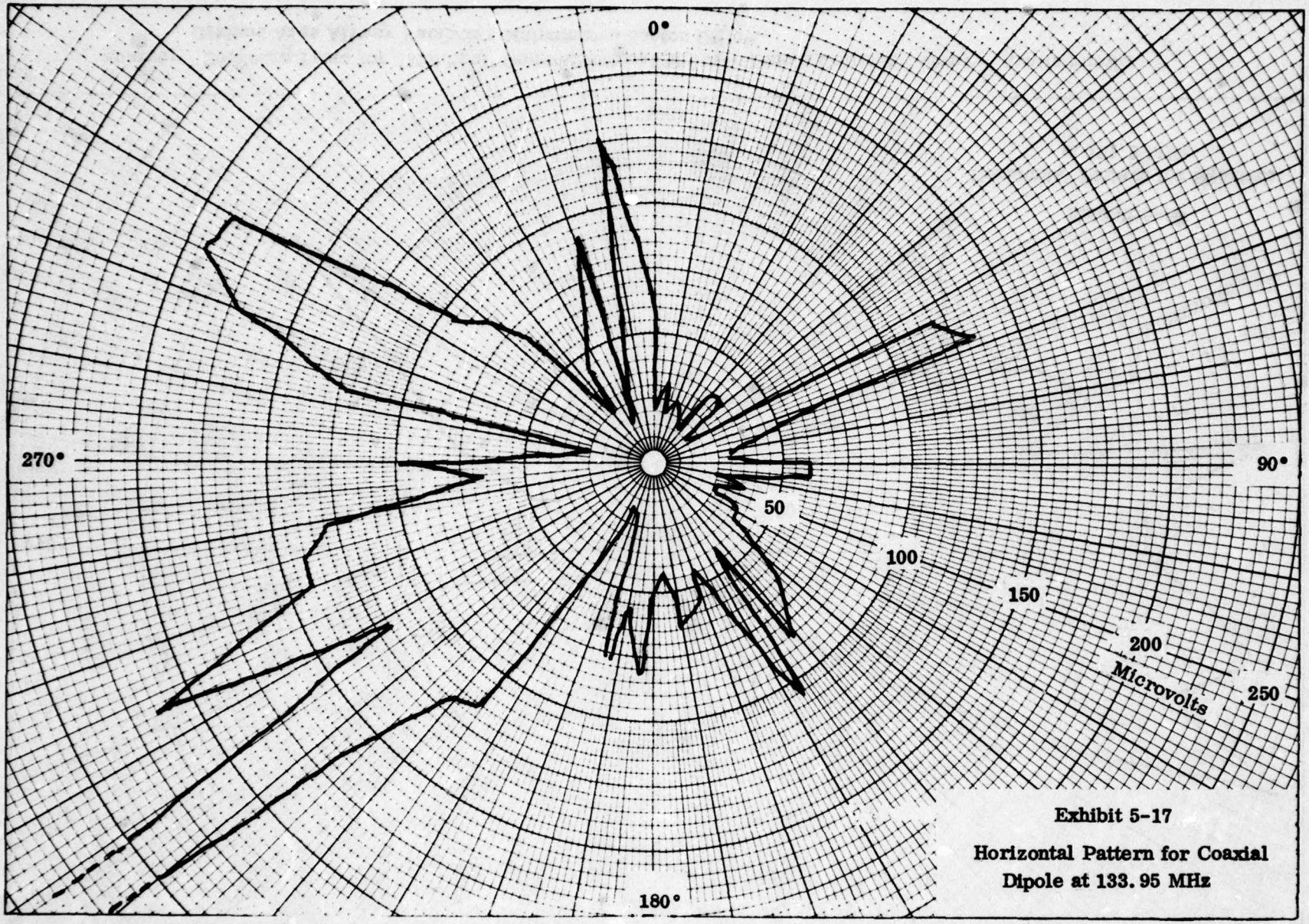


Exhibit 5-17

Horizontal Pattern for Coaxial Dipole at 133.95 MHz

Source: "Coverage Tests for 'Muldipol' Omnidirectional Multiple Dipole Collinear Array," Austin Smith, Oakland Area Airway Facilities Maintenance Sector Office.

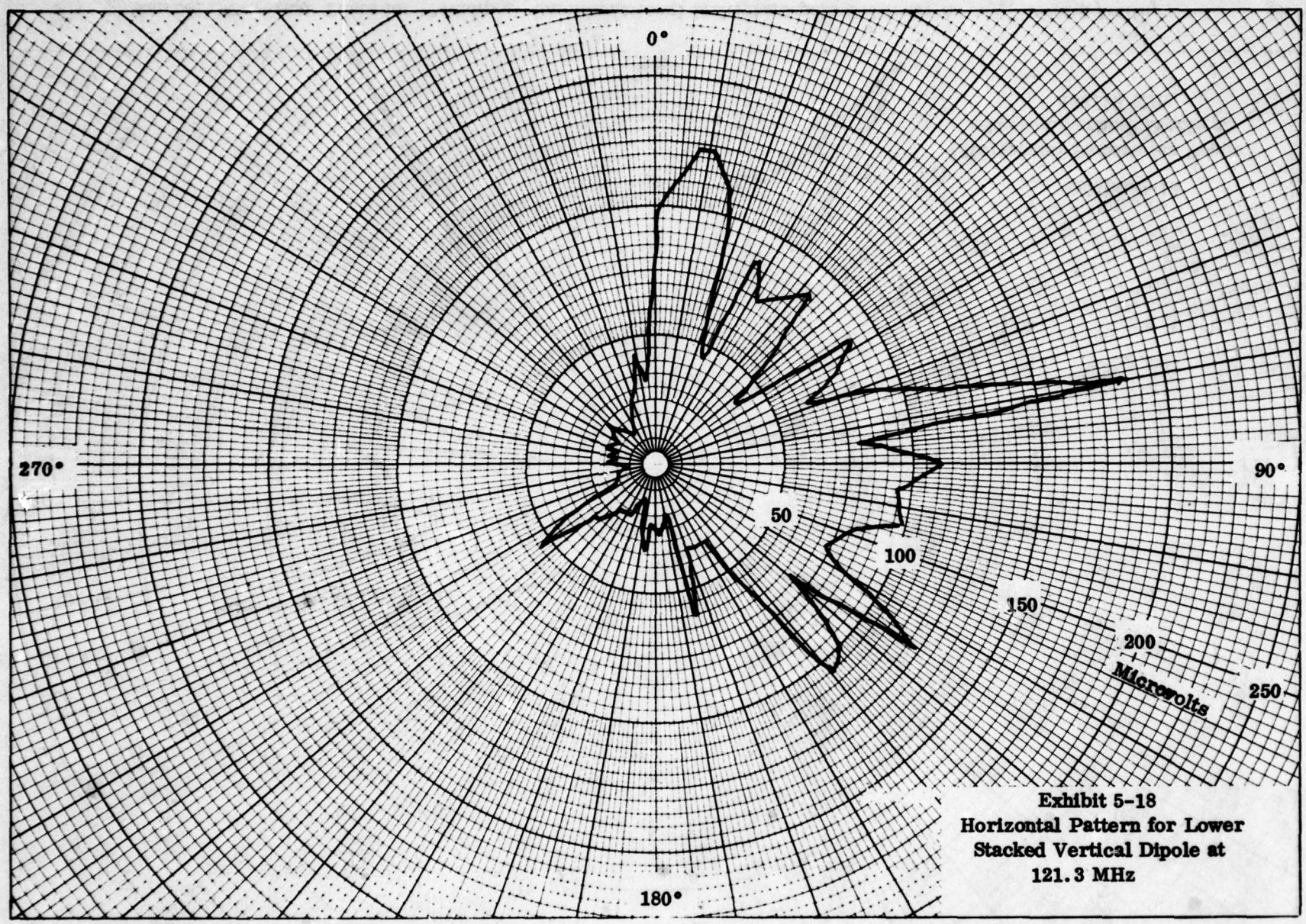


Exhibit 5-18
Horizontal Pattern for Lower Stacked Vertical Dipole at 121.3 MHz

Source: "Coverage Tests for 'Muldipol' Omnidirectional Multiple Dipole Collinear Array," Austin Smith, Oakland Area Airway Facilities Maintenance Sector Office.

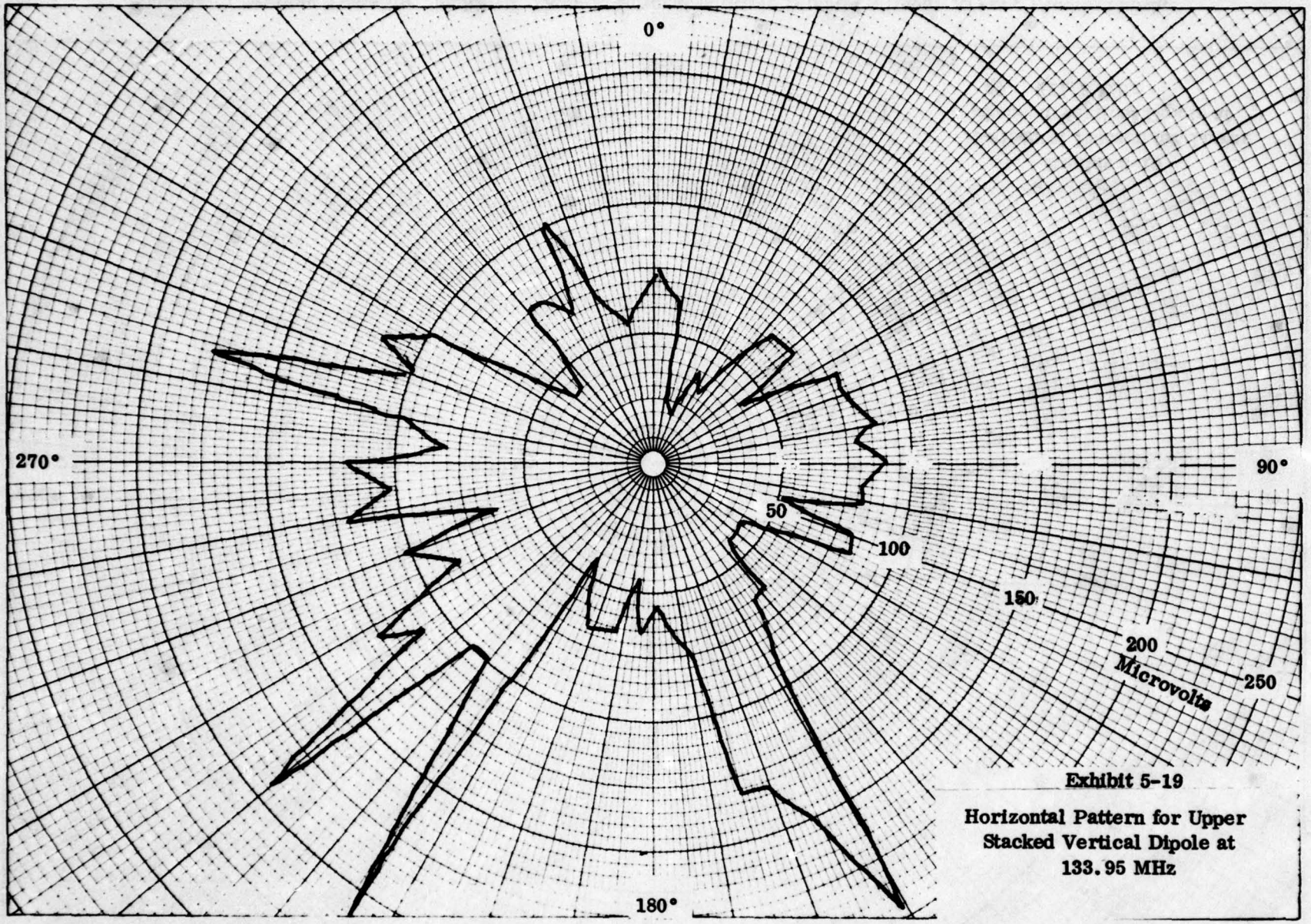


Exhibit 5-19

Horizontal Pattern for Upper Stacked Vertical Dipole at 133.95 MHz

Source: "Coverage Tests for 'Muldipol' Omnidirectional Multiple Dipole Collinear Array," Austin Smith, Oakland Area Airway Facilities Maintenance Sector Office.

Exhibit 5-20

OAKLAND BAY TRACON ANTENNA ENVIRONMENT
(TOP VIEW)

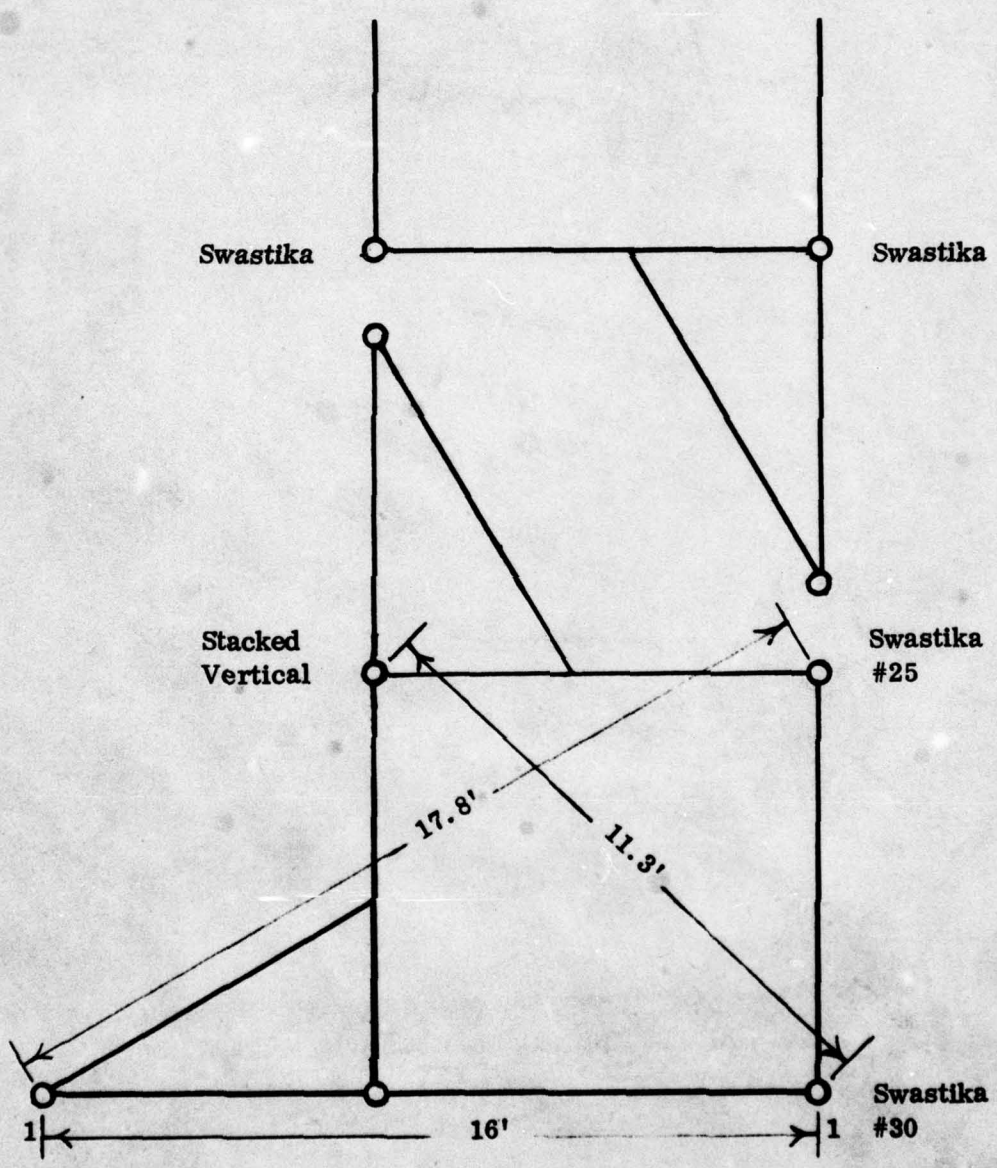


Exhibit 5-21

OAKLAND BAY TRACON (TRANSMITTER ANTENNAS)



As part of the present program, a series of tests were conducted at the NAFEC Antenna Test Range in order to identify the sources of distortion. The test range configuration is shown in Exhibit 5-22. The receiver site includes a rotatable pedestal with which pattern measurements are collected. Exhibit 5-23 shows the test bed in which two wooden 2-by 4-inch cross arms were mounted on the turntable in order to allow multiple antenna configurations. A series of measurements were made with antenna separations of 2, 4, and 8 feet for various antennas.

Exhibit 5-24 shows the standard circular free space pattern obtained at the test range for a vertical dipole mounted in the center of the turntable. Exhibit 5-25 shows the effects obtained by adding two parasitic elements (shorted dipole antennas) of the same length (approx. 1/2 wavelength) mounted in line from the center mounted driven antenna at distances of $\lambda/4$ and $\lambda/2$. The 5 db contour represents the free space pattern so that there is a +3 db enhancement of signal as well as a -9 db null as shown. The parasitic elements are excited and re-radiate causing interference with the radiation pattern of the driven elements. The resultant field is a function of the length of the parasitic elements, and their separation from the driven antenna.

Exhibit 5-26 shows a measurement for a single swastika antenna mounted 4 feet from the center of the turntable in an offset configuration. There is a 2.5 to 3 db distortion caused by the asymmetry of the antenna in relation to the antenna pedestal.

Exhibit 5-27 shows the results of adding three metallic mounting pipes (normally employed to mount swastika antennas). The patterns show a null depth of 8.5 db and an enhancement of almost 5 db.

Exhibit 5-28 shows a measurement of four swastika antennas where the measurement has been performed for both terminating (in 50 ohms) and open circuiting the parasitic elements. The distortion effects caused by the mounting pipes alone as shown in Exhibit 5-27 are comparable to the effects with the four swastikas in position.

Exhibit 5-29 shows the results of measurements for a configuration of eight antennas of various types (swastika and vertical dipoles). The driven element is a VHF dipole antenna. The distortion is not as severe as for the previous measurements. No metallic mounts were employed (except for the one swastika in the

Exhibit 5-22

PROFILE OF NAFEC ANTENA TEST RANGE

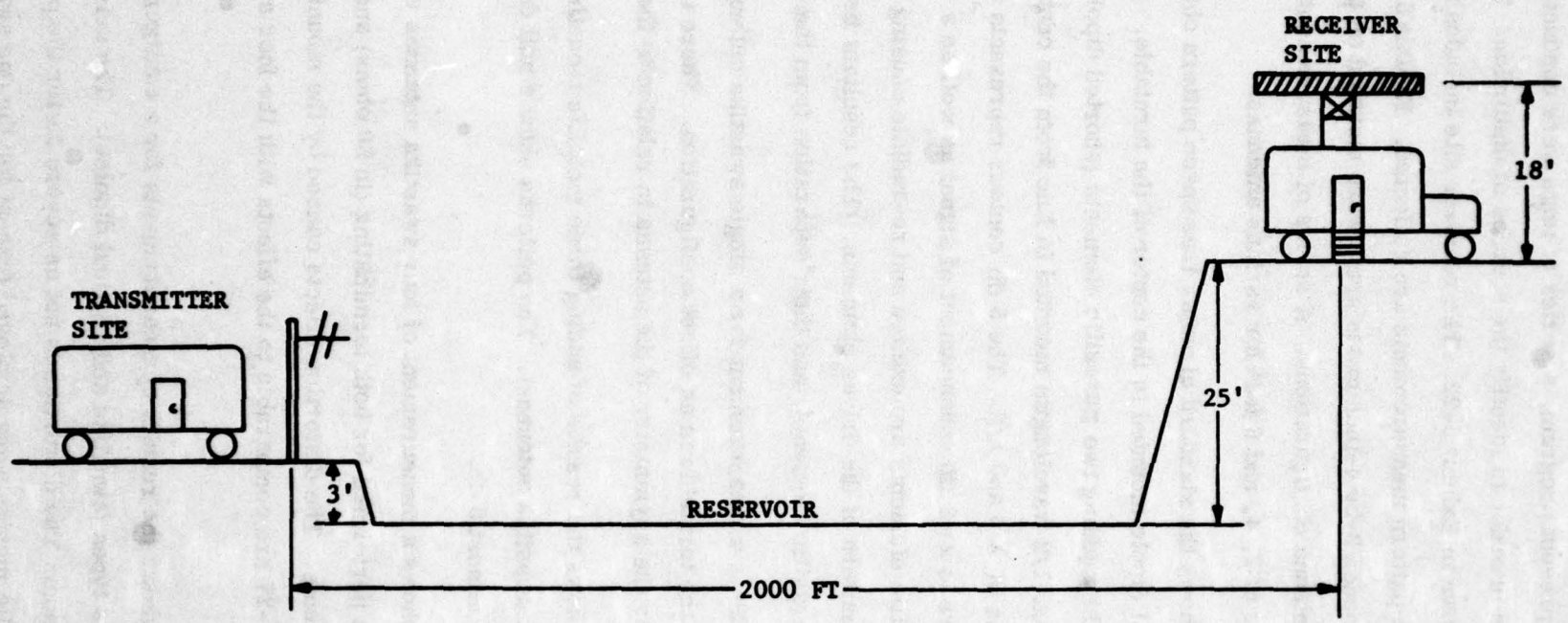


Exhibit 5-23

HORIZONTAL PATTERN MEASUREMENT CONFIGURATION

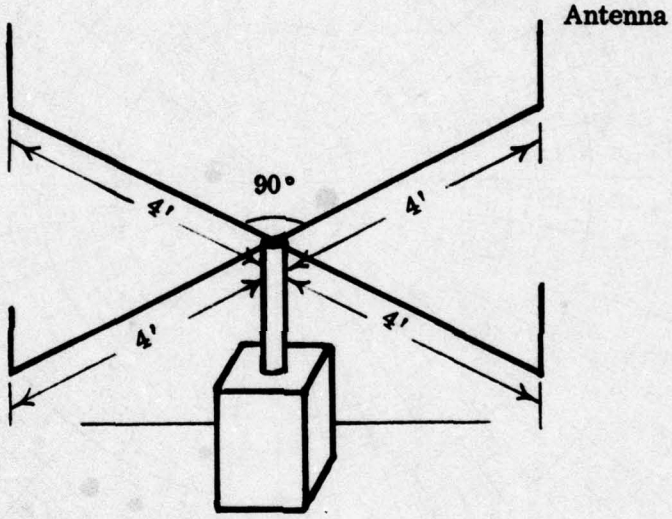


Exhibit 5-24

STANDARD PATTERN, VERTICAL DIPOLE ANTENNA

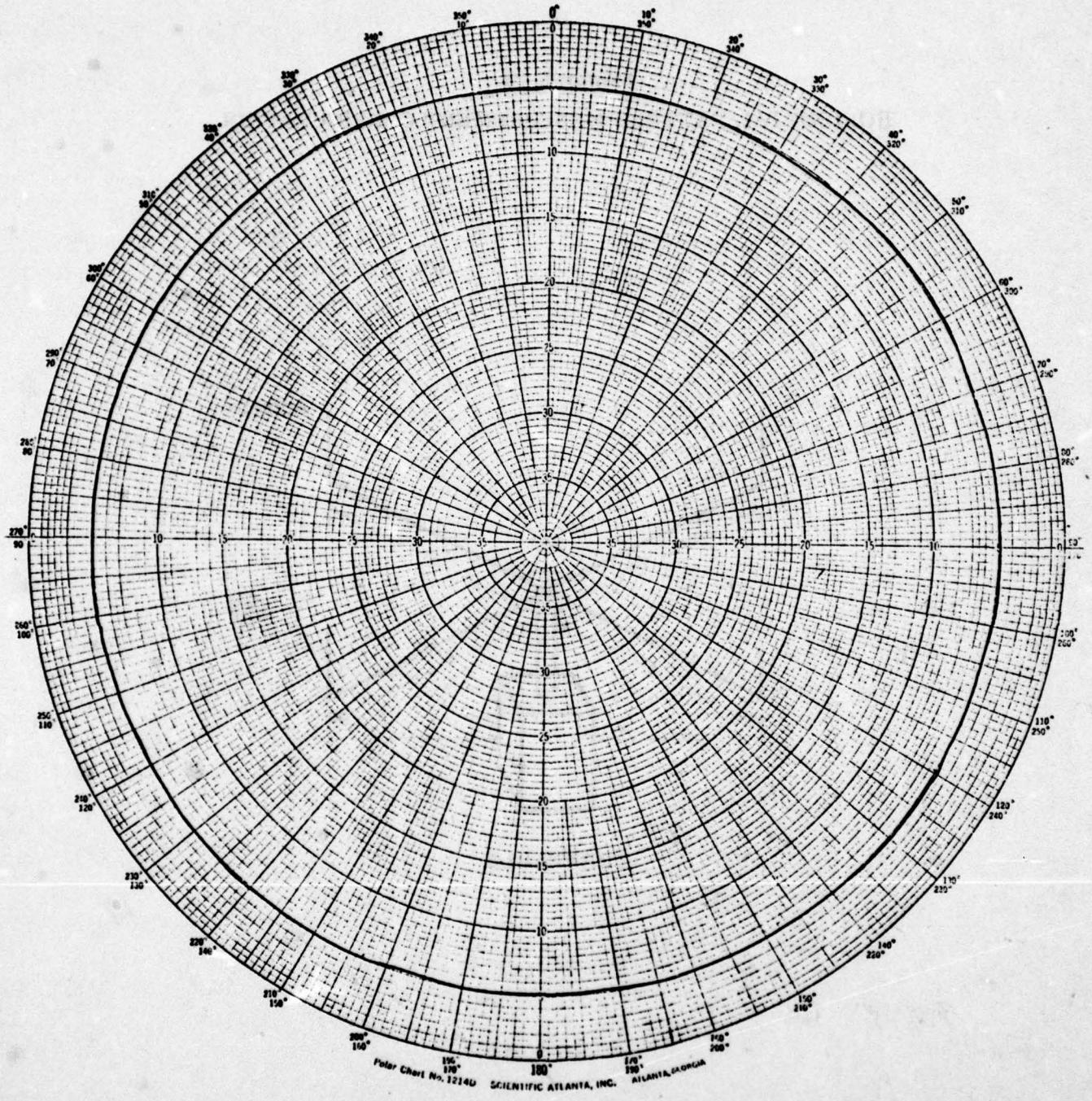


Exhibit 5-25

PARASITIC ANTENNA EFFECTS ON HORIZONTAL PATTERN

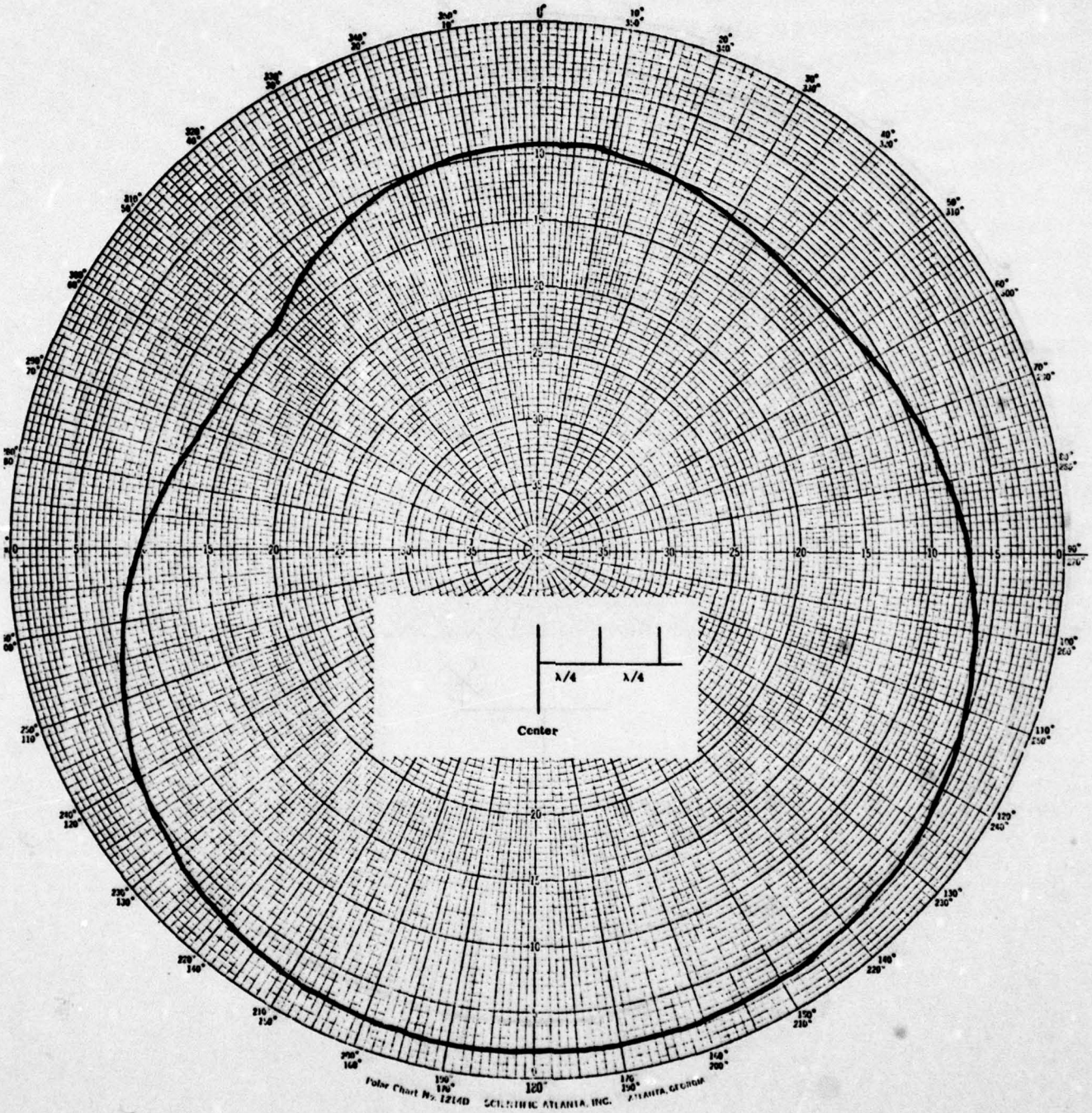


Exhibit 5-26

OFFSET SINGLE SWASTIKA

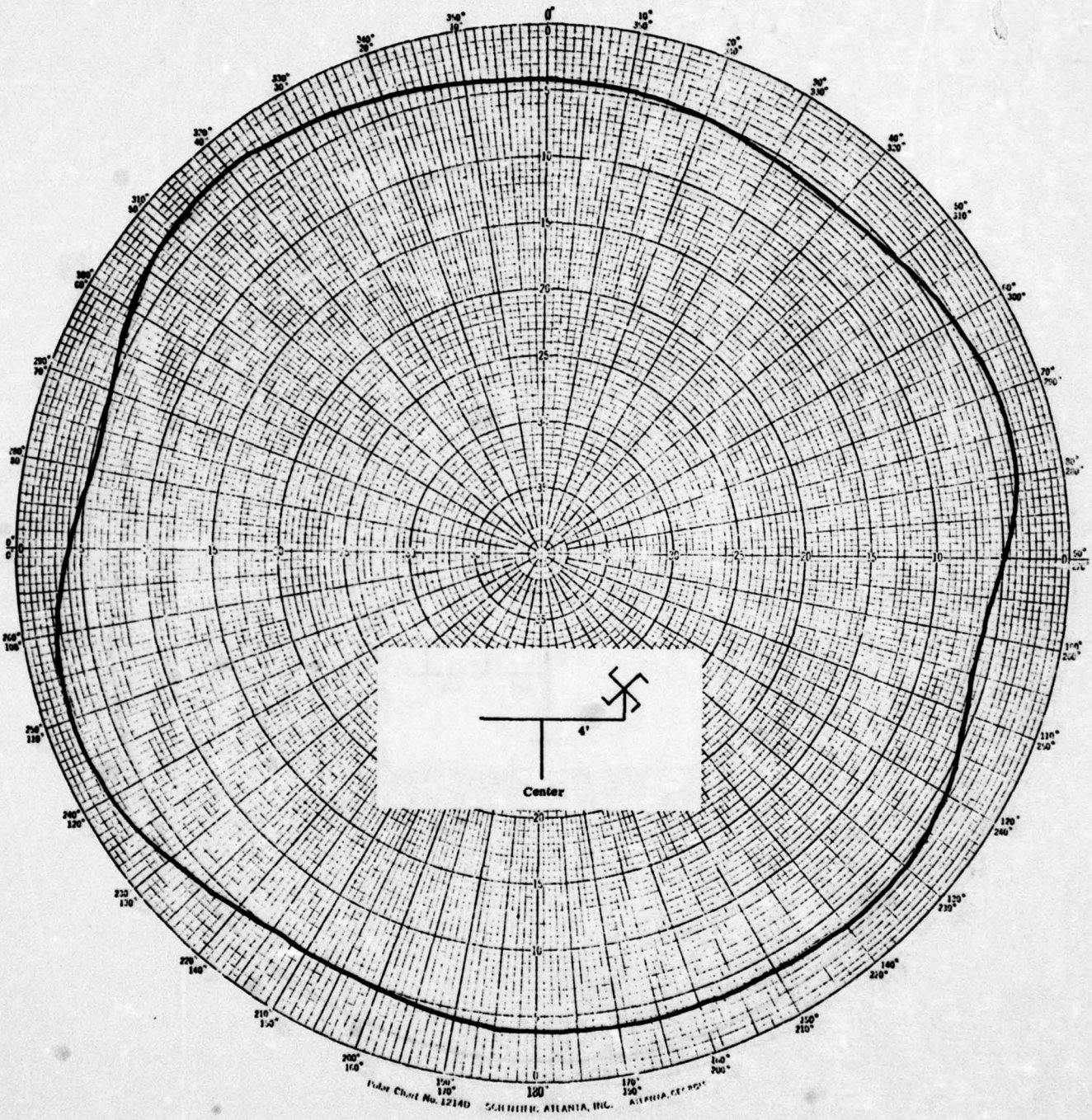


Exhibit 5-27

PARASITIC EFFECTS: MOUNTING PIPES

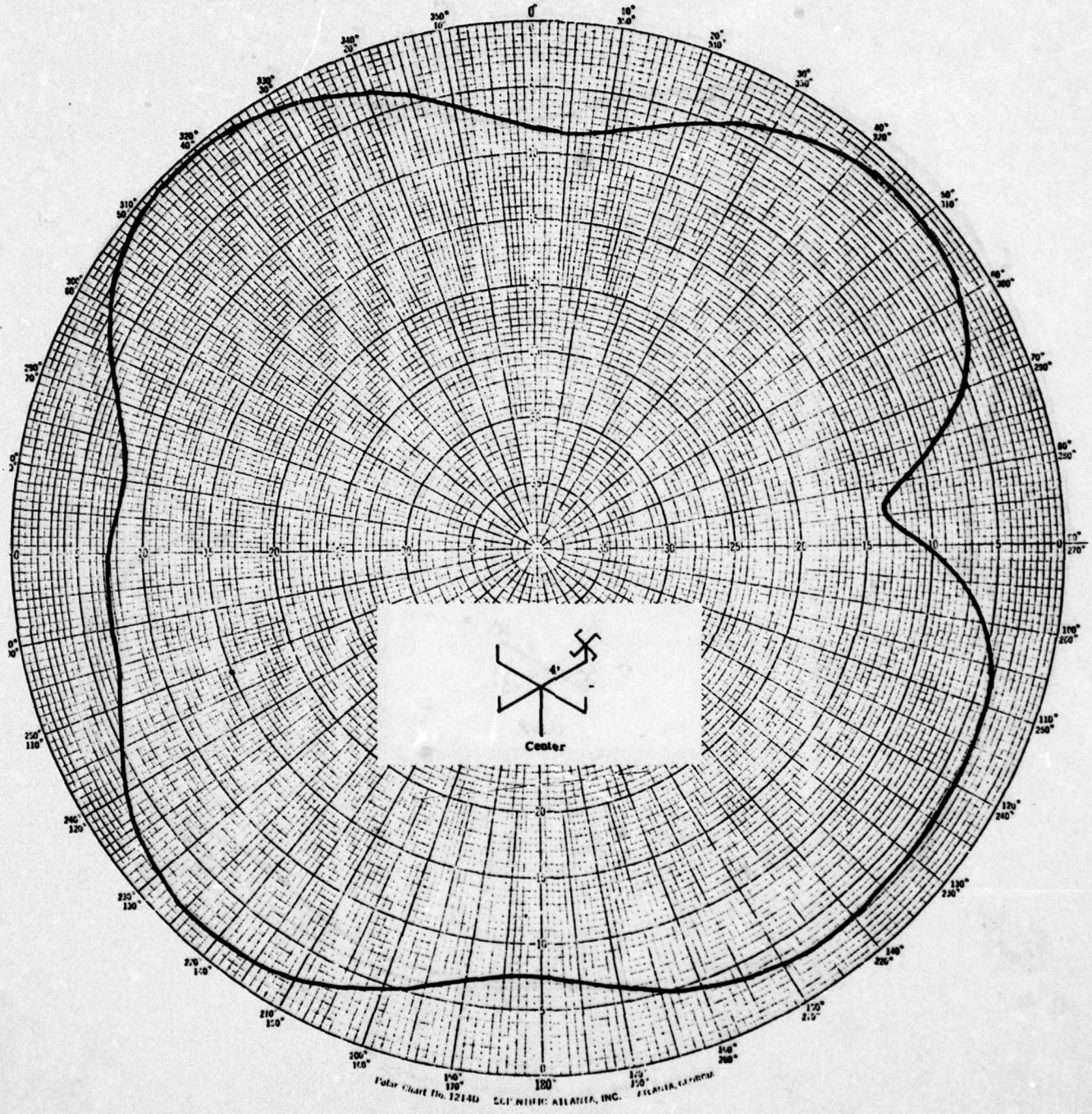


Exhibit 5 28

PARASITIC ANTENNA EFFECTS : FOUR SWASTIKAS

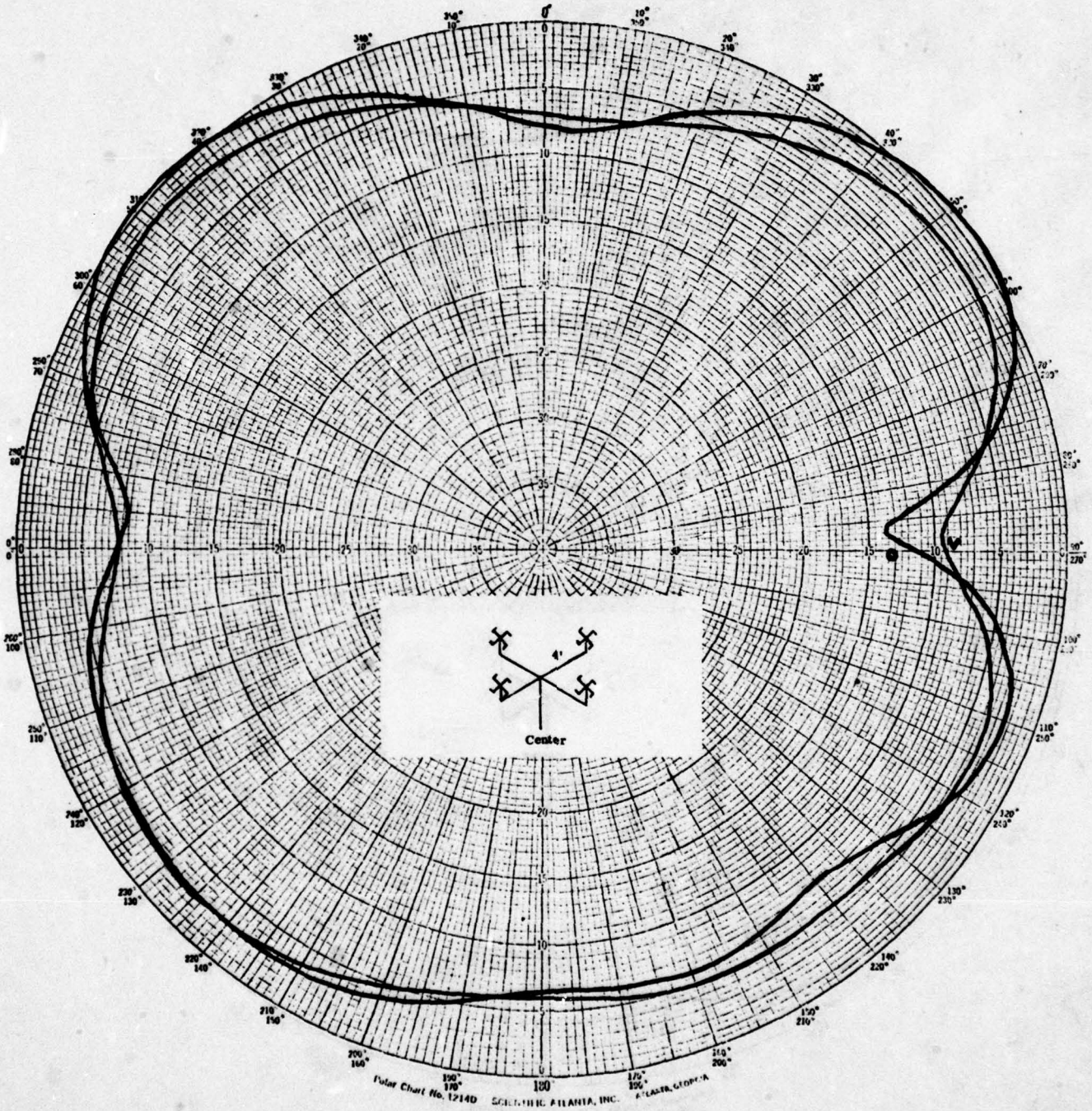
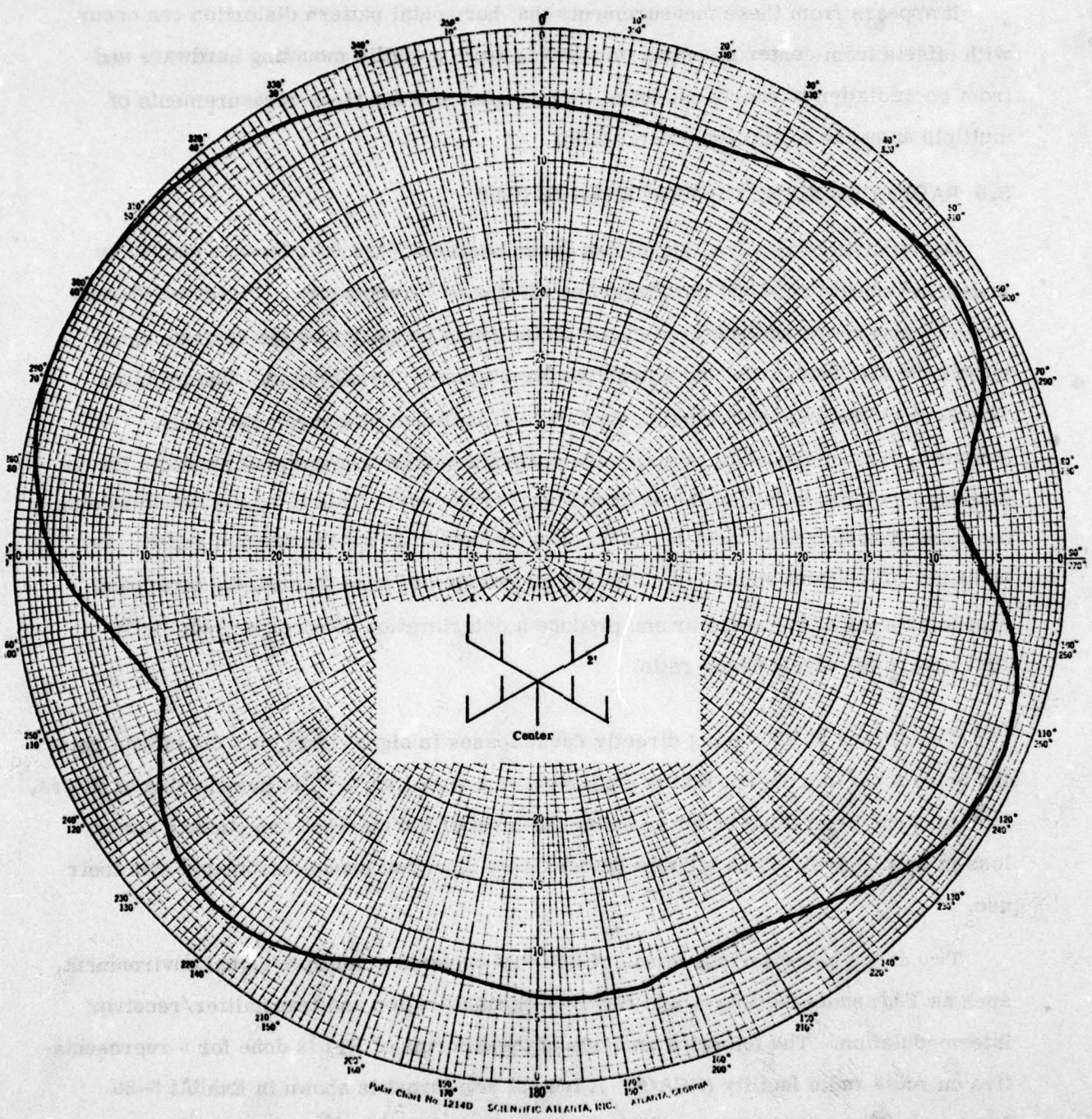


Exhibit 5-29

PARASITIC EFFECTS: EIGHT ANTENNAS



configuration). The antennas were all terminated in 50 ohms, while those parastic elements shown in Exhibit 5-25 were shorted.

It appears from these measurements that horizontal pattern distortion can occur with offsets from center mounting on towers, from metallic mounting hardware and from re-radiation of nearby antennas. The signal null for those measurements of multiple antennas is approximately -9 db.

5.6 RADIO FREQUENCY INTERFERENCE (RFI)

Degradation of received signal can occur because of the interference caused by undesired signals either at on-channel or off-channel frequencies. Direct co-channel interference where an undesired signal on the same frequency as the desired signal enters the receiver, presents a problem for frequency management. The problem is solved by making co-channel assignments at sufficient distance separation. However, it is also possible through the generation of intermodulation products for an interfering signal to fall on the desired signal frequency. This is equivalent to raising the noise (interference) level of the receiver and masking out the desired signal. In addition, off channel signals of sufficient magnitude can pass through the broadband characteristics of the receiver and produce a deterioration of receiver sensitivity that lowers the signal/noise ratio.

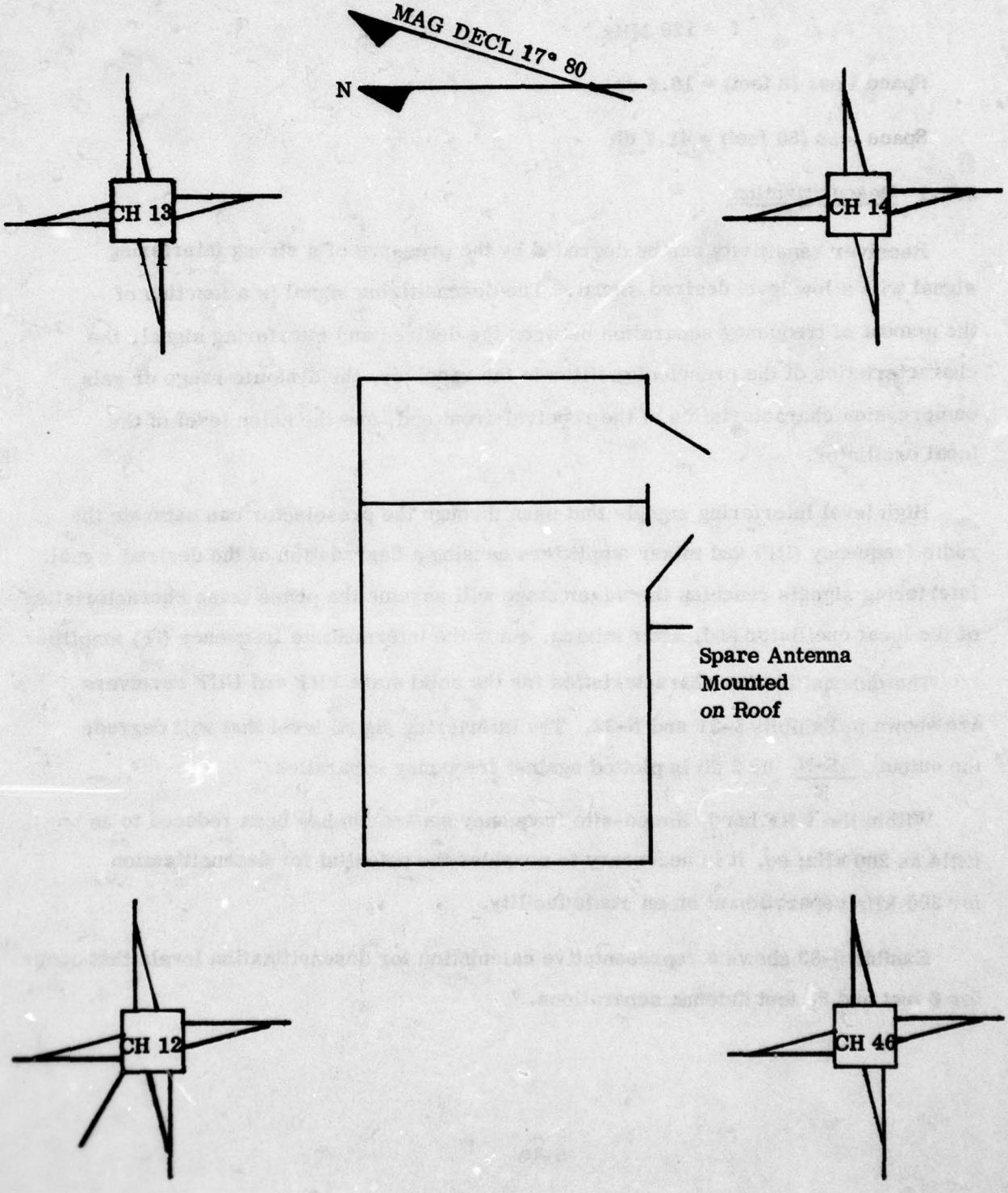
The effects of RFI do not directly cause losses in signal level, but the effects raise the noise level to a degree that is equivalent to a signal loss. The introduction of filters, isolators and other devices for reducing the level of interference can cause a direct loss in signal level, since all such devices have insertion losses associated with their use.

Two of the more serious forms of RFI that occur in a multiple signal environment, such as FAA radio facilities, are receiver desensitization and transmitter/receiver intermodulation. The following analysis of these forms of RFI is done for a representative en route radio facility (RCAG). A typical site layout is shown in Exhibit 5-30 for Angels Camp located in the Oakland Center Area (ZOA). The minimum distance criteria for a standard configuration is as follows:

Exhibit 5-30

ANGELS CAMP RCAG

SITE II



(1) Antenna Separation--8 feet

(2) Tower Separation--80 feet

Since the space loss of radio signals capable of generating interference determines the level of interfering signal, the calculations are carried out for a frequency of 120 MHz, which represents a worst case condition.

$f = 120$ MHz

Space Loss (8 feet) = 18.6 db

Space loss (80 feet) = 41.7 db

5.6.1 Desensitization

Receiver sensitivity can be degraded by the presence of a strong interfering signal with a low level desired signal. The desensitizing signal is a function of the amount of frequency separation between the desired and interfering signal, the characteristics of the preselector filter in the receiver, the dynamic range or gain compression characteristics of the receiver front end, and the noise level of the local oscillator.

High level interfering signals that pass through the preselector can saturate the radio frequency (RF) and mixer amplifiers causing a degradation of the desired signal. Interfering signals reaching the mixer stage will assume the phase noise characteristics of the local oscillator and, after mixing, enter the intermediate frequency (IF) amplifier.

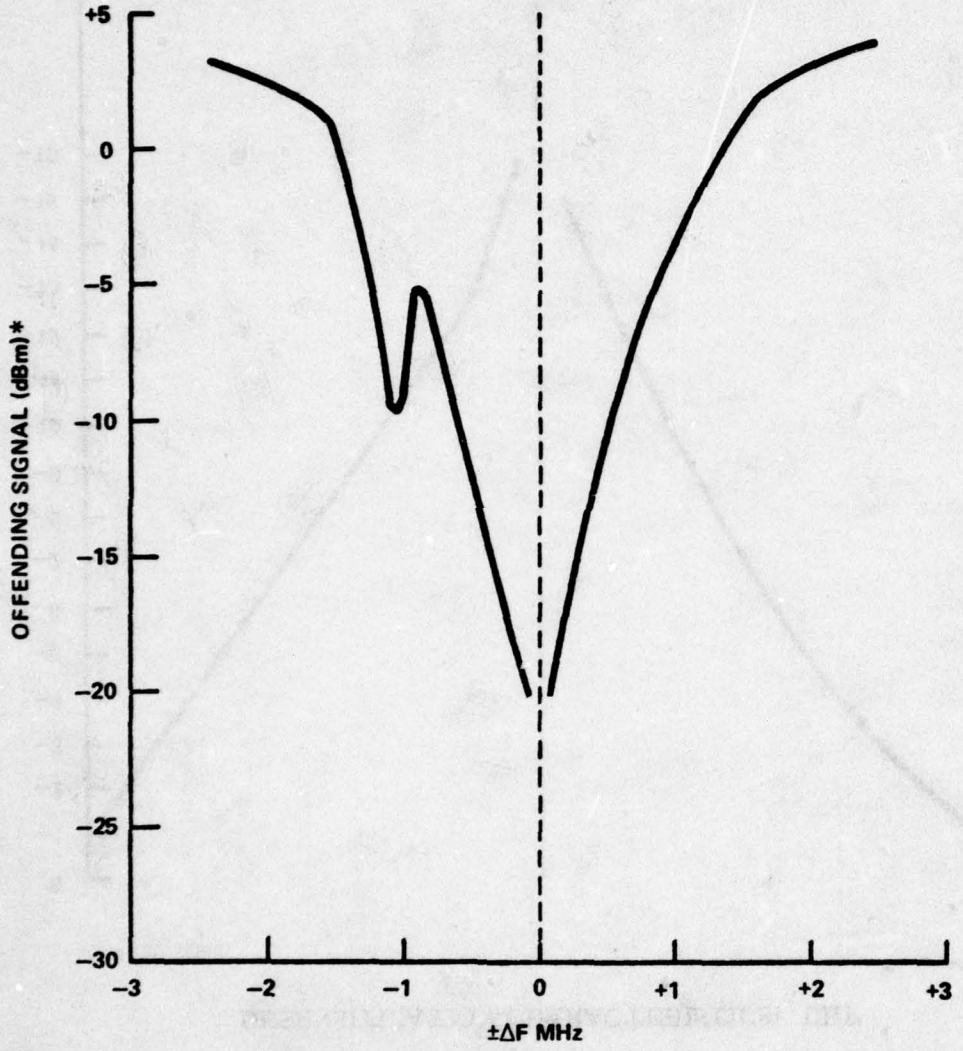
The desensitization characteristics for the solid state VHF and UHF receivers are shown in Exhibits 5-31 and 5-32. The interfering signal level that will degrade the output $\frac{S+N}{N}$ by 2 db is plotted against frequency separation.

Within the VHF band, the co-site frequency separation has been reduced to as little as 200 kHz; so, it is necessary to consider the potential for desensitization for 200 kHz separation at an en route facility.

Exhibit 5-33 shows a representative calculation for desensitization levels that occur for 8 feet and 80 feet antenna separations.

Exhibit 5-31

DESENSITIZATION CHARACTERISTICS: VHF



*Level of offending signal necessary to cause a 2 db reduction in the desired signal.

Exhibit 5-32

DESENSITIZATION CHARACTERISTICS: UHF

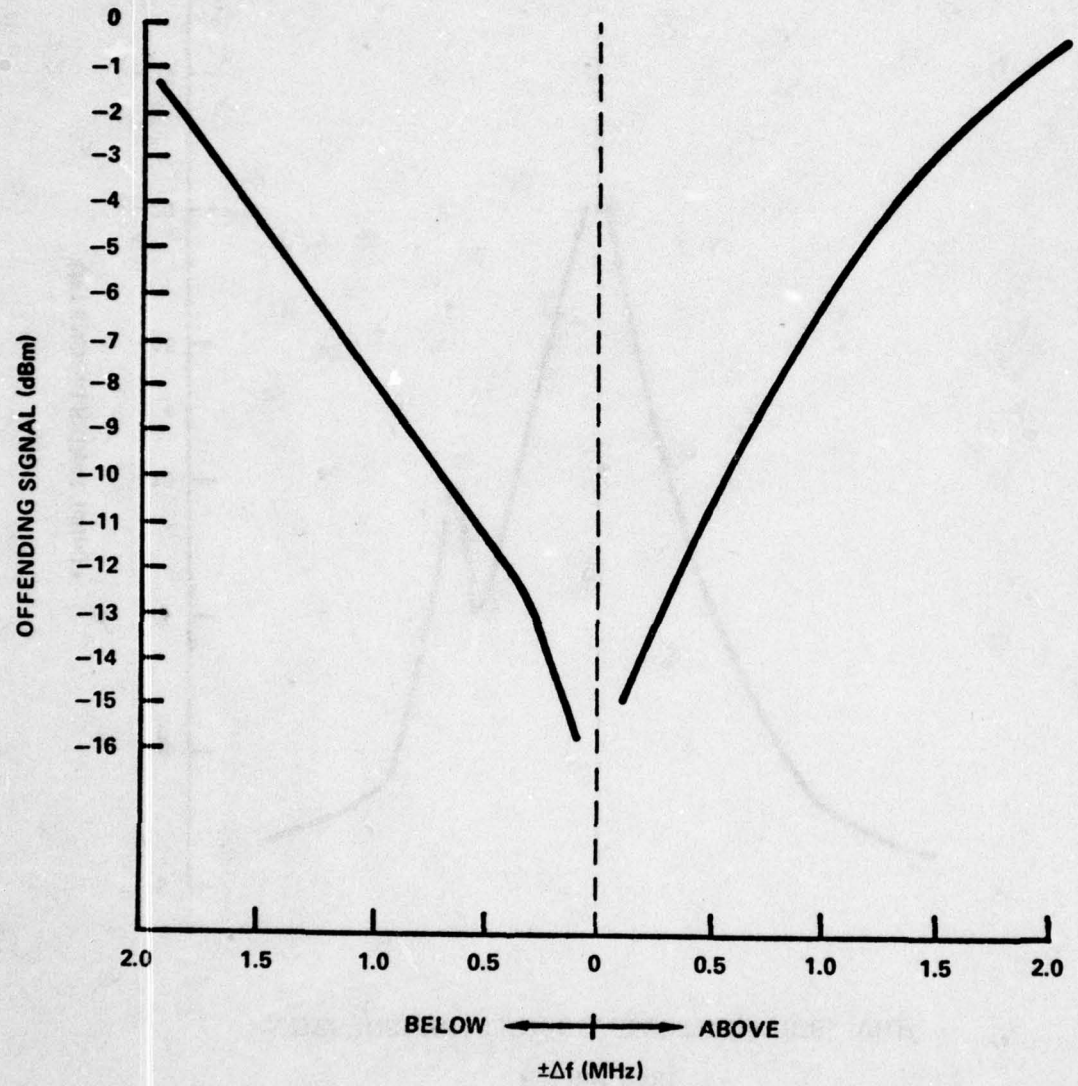
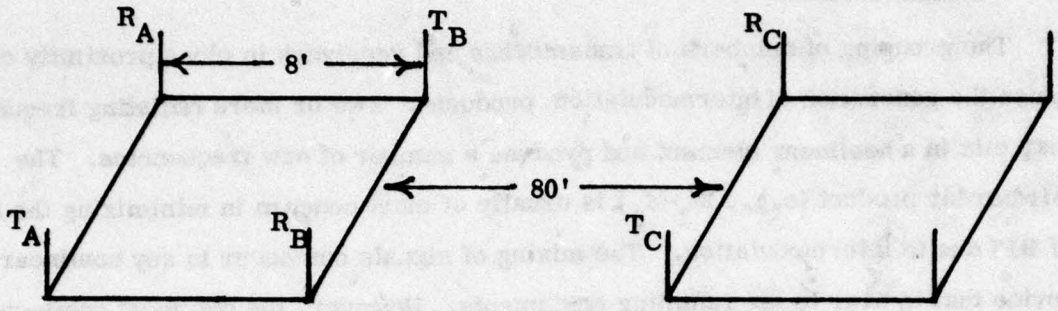


Exhibit 5-33

RECEIVER DESENSITIZATION



CASE: (1) T_B R_A Low VHF BAND ΔF = 200 kHz

(2) T_B R_C

	CASE (1)	CASE (2)
Transmitter B Power (50 watts)	47 dbm	47 dbm
T_B Cable Loss	- 2 db	- 2 db
T_B Antenna Gain	0 db	0 db
T_B - R_A Space Loss	- 18.6 db	
T_B - R_C Space Loss		- 41.7 db
R_A; R_C Antenna Gain	0 db	0 db
R_A; R_C Cable Loss	- 2 db	- 2 db
* * *		
Interfering Signal Level	24.4 dbm	1.3 dbm
Desensitization Level (ΔF = 200 kHz) (Exhibit 5-31)	- 20 dbm	- 20 dbm
Excess Signal Interference	4.4 dbm	18.7 dbm

For 80 feet separation, the frequency separation should be greater than 1.5 MHz to avoid receiver desensitization (2 db). A reduction in power of the transmitted signal level to -5.7 dbm allows a frequency separation of 1.2 MHz.

5.6.2 Intermodulation

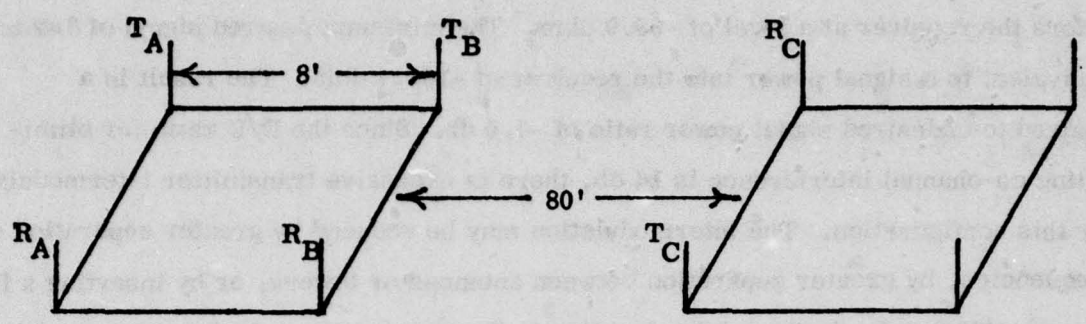
The grouping of numbers of transmitters and receivers in close proximity can cause the generation of intermodulation products. Two or more radiating frequencies may mix in a nonlinear element and produce a number of new frequencies. The third order product (e.g., $2f_1 - f_2$) is usually of most concern in minimizing the effects of RFI due to intermodulation. The mixing of signals can occur in any nonlinear device that is near to the radiating equipments. However, the two most common locations are the transmitter final amplifer, which results in transmitter intermodulation, and the receiver front end, which results in receiver intermodulation. The configurations for radio communications employed by FAA are susceptible to both forms of intermodulation. Whenever possible, frequency management is applied to eliminate the use of a susceptible receiver frequency or lower the interfering signal level at a particular location. If the product level generated is excessive and will cause interference, the physical separation between antennas must be increased or appropriate filtering devices must be employed.

5.6.2.1 Transmitter Intermodulation. Exhibit 5-34 shows a calculation for transmitter intermodulation that is representative of FAA en route configurations. The antennas are separated by a minimum of 8 feet and the towers are separated by a minimum of 80 feet as shown in the exhibit. For this example, it is assumed that transmitter A and transmitter B are radiating to produce a third order product (2B-A) that enters receiver C.

Again, as in previous examples, low VHF frequencies are assumed to be the worst case condition. The transmitter A signal enters the transmitter B final amplifier through the transmitter B antenna. The intermodulation product (2B-A) generated falls on the frequency of receiver C. The process of intermodulation results in a conversion loss so that the product level generated is below that of interfering signal (from transmitter A). Data for the VHF and UHF solid state transmitter final

Exhibit 5-34

TRANSMITTER INTERMODULATION



CASE: T_A T_B R_C Low VHF BAND ΔF = 500 kHz

T_A Power Out (50 watts)	47 dbm
T_A Cable Loss	- 2 db
T_A Antenna Gain	0 db
T_A - T_B Space Loss	- 18.6 db
T_B Antenna Gain	0 db
T_B Cable Loss	- 2 db
T_B Conversion Loss	- 31 db
T_B Cable Loss	- 2 db
T_B Antenna Gain	0 db
T_B - R_C Space Loss	- 41.7 db
R_C Antenna Gain	0 db
R_C Cable Loss	- 2 db

* * *

Interfering Signal Level	- 52.3 dbm
Desired Signal Level (3 μv)	- 103.4 dbm
$\frac{\text{Desired}}{\text{Undesired}}$ Signal Ratio	- 51.1 db
$\frac{\text{Desired}}{\text{Undesired}}$ Signal Ratio (Specified)	14 db

amplifiers and exciters are shown in Exhibits 5-35 through 5-38. The product level in db below the interfering signal level is shown as a function of frequency separation.

As is noted in Exhibit 5-34, the resulting intermodulation interference signal enters the receiver at a level of -98.9 dbm. The minimum desired signal of 3 μv is equivalent to a signal power into the receiver of -103.4 dbm. The result is a desired to undesired signal power ratio of -4.5 db. Since the D/U ratio for eliminating co-channel interference is 14 db, there is excessive transmitter intermodulation for this configuration. The intermodulation may be reduced by greater separation of frequencies, by greater separation between antennas or towers, or by inserting a filter or an isolator prior to the mixing location in the transmitter, which is between antenna and transmitter output.

5.6.2.2 Receiver Intermodulation. Two transmitted signals separated by ΔF and $2\Delta F$ from the receiver center frequency may enter a receiver and mix in its front end and generate a third order intermodulation product ($2\Delta F - \Delta F$).

Exhibit 5-39 shows a calculation for a representative antenna configuration. As shown, transmitted signal levels of -1.3 dbm enter receiver C. According to the receiver intermodulation characteristics shown in Exhibits 5-40 and 5-41 for a frequency separation of 500 kHz, the interfering signal level should be less than -41. dBm for a $\frac{S_o + N_o + I_o}{N_o + I_o} = 10$ db. Therefore, undesirable receiver intermodulation exists for the configuration and conditions shown.

Receiver intermodulation may be reduced by a greater separation of frequencies, by a greater separation between antennas, and by the insertion of a filter prior to the mixing location in the receiver.

In summary, it appears that conditions exist for the generation of excessive levels of RFI at FAA en route facilities. Problems can arise due to receiver desensitization, transmitter intermodulation, and receiver intermodulation. Note that for RFI to occur, the offending sources of radiation (i.e., the transmitters) as well as the target receiver must be in use so that, in practice, such problems are likely to be intermittent. Additionally, for the case of intermodulation interference, there may be some freedom of choice in the assignment and shifting of radio frequencies.

Exhibit 5-35

TRANSMITTER AN/GRT-21 THIRD-ORDER INTERMODULATION PRODUCT (EXCITER ALONE)

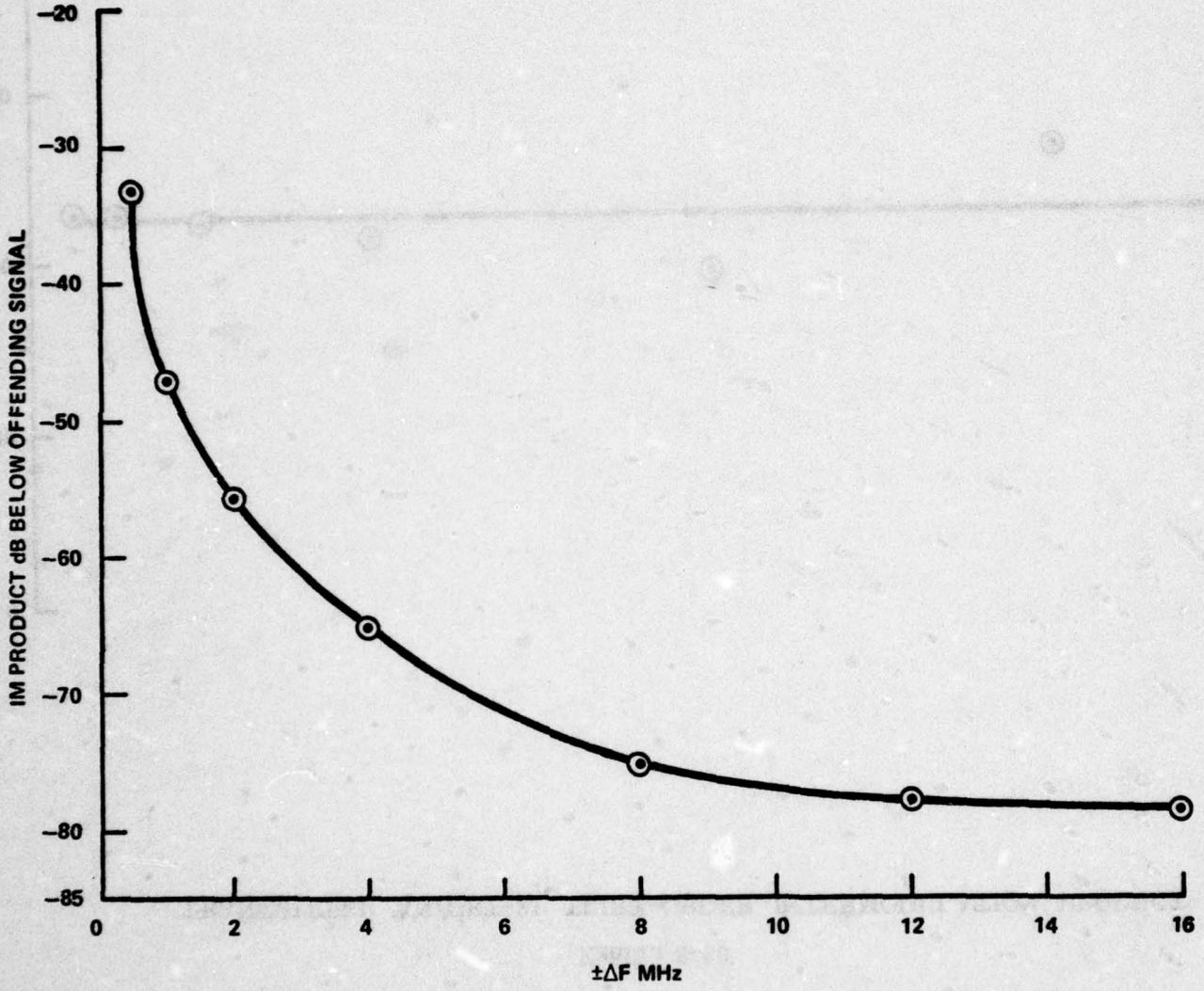


Exhibit 5-36

TRANSMITTER AN/GRT-21 THIRD-ORDER INTERMODULATION PRODUCT

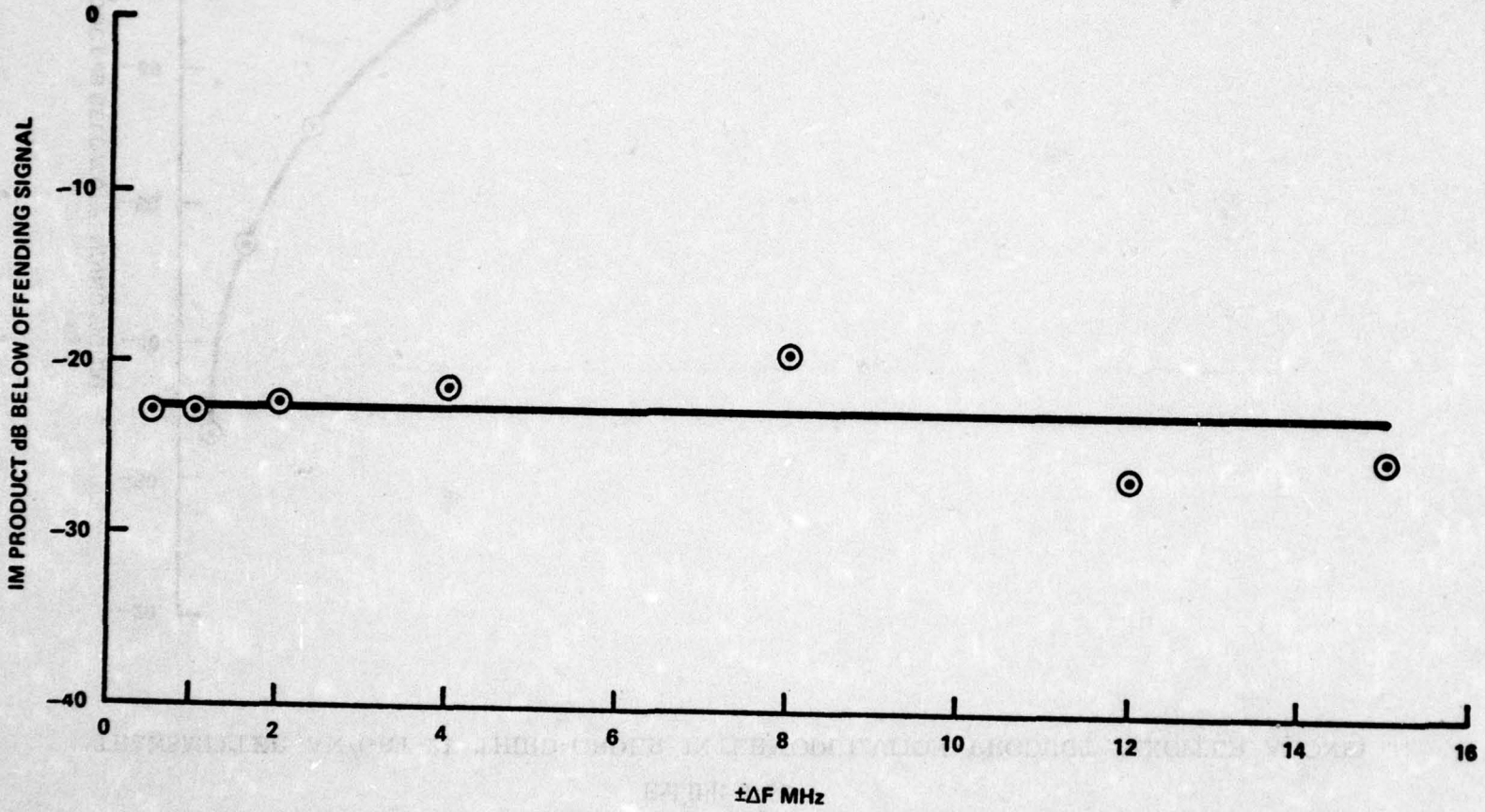


Exhibit 5-37

TRANSMITTER AN/GRT-22 THIRD-ORDER INTERMODULATION PRODUCT

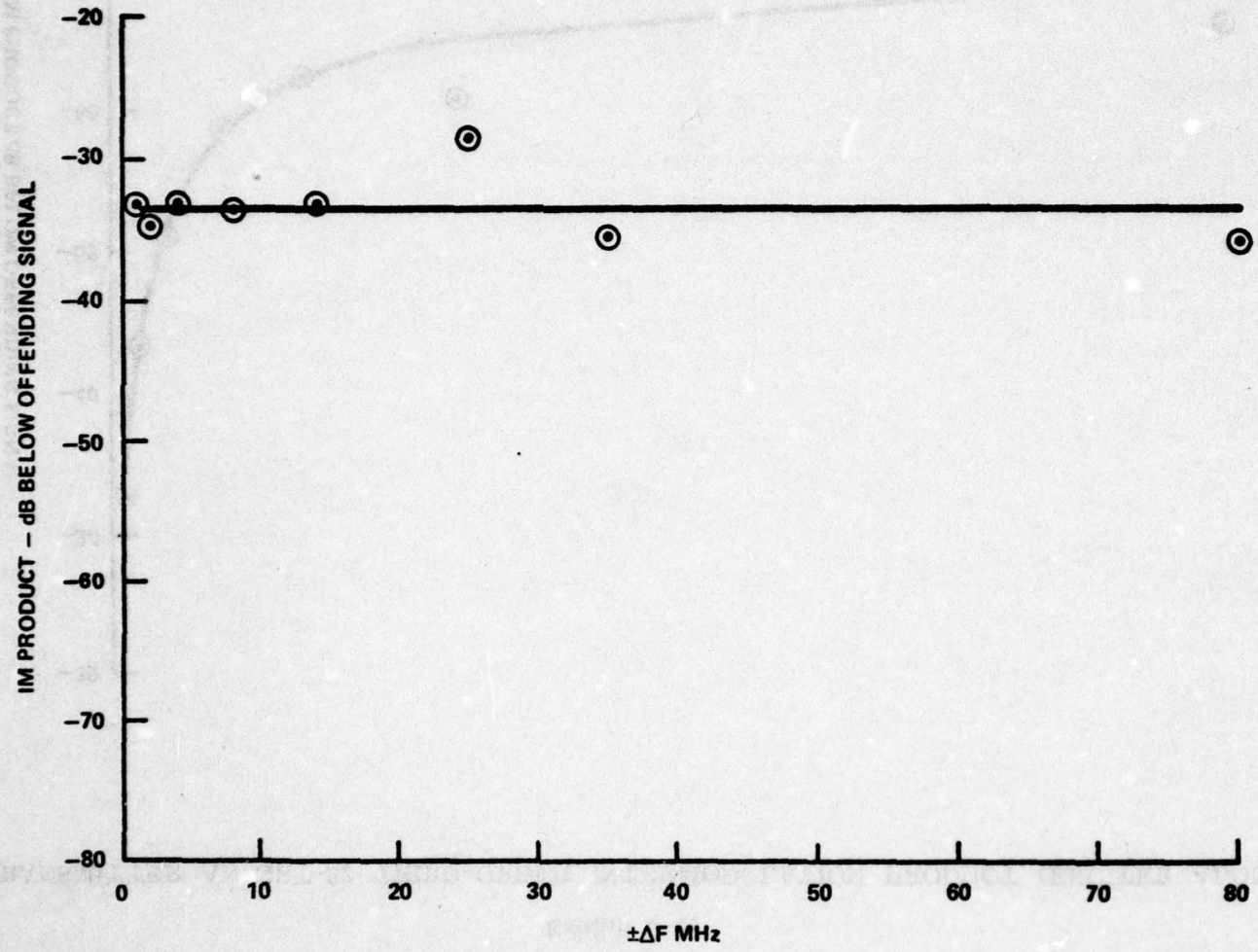


Exhibit 5-38

TRANSMITTER AN/GRT-22 THIRD-ORDER INTERMODULATION PRODUCT (EXCITER ALONE)

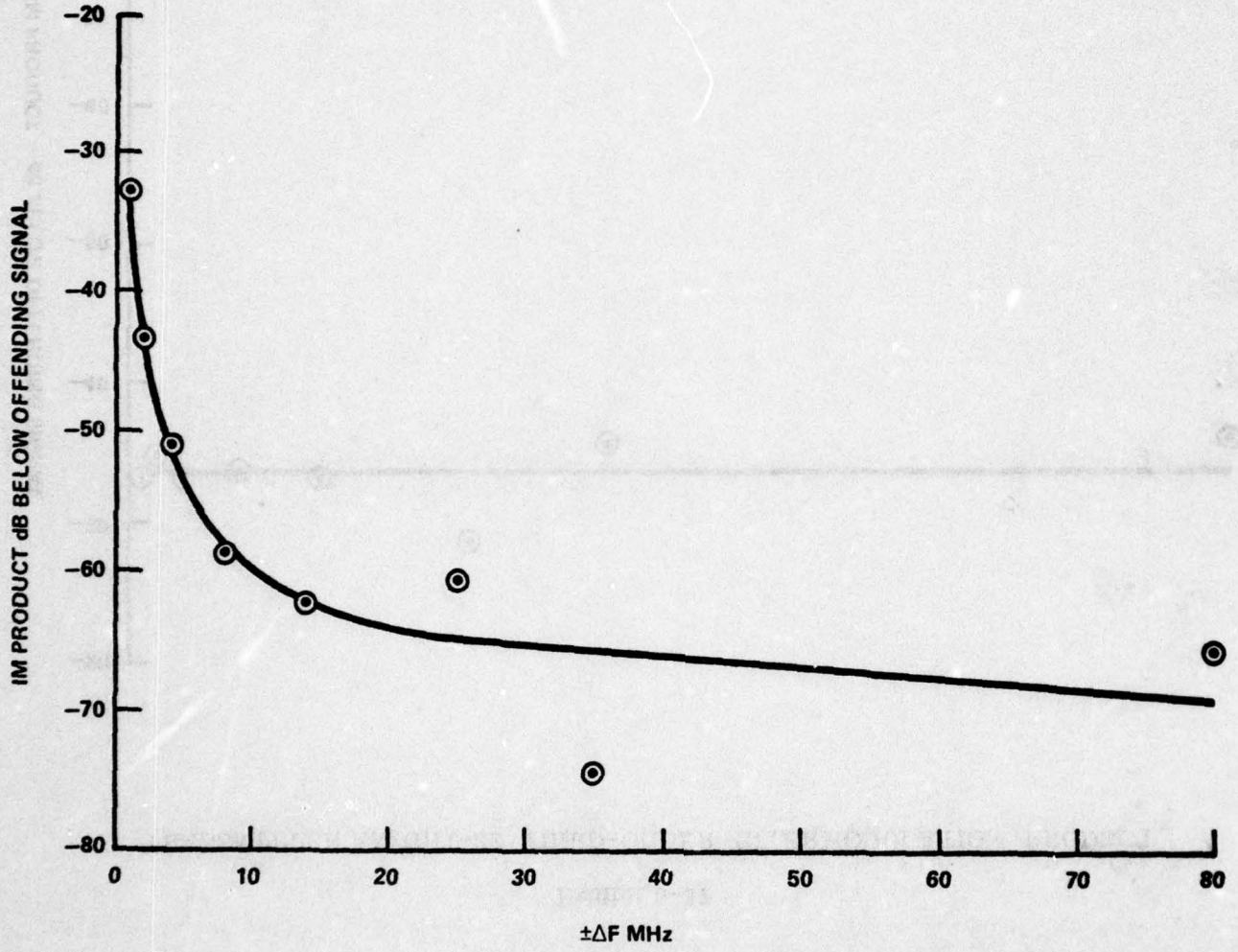
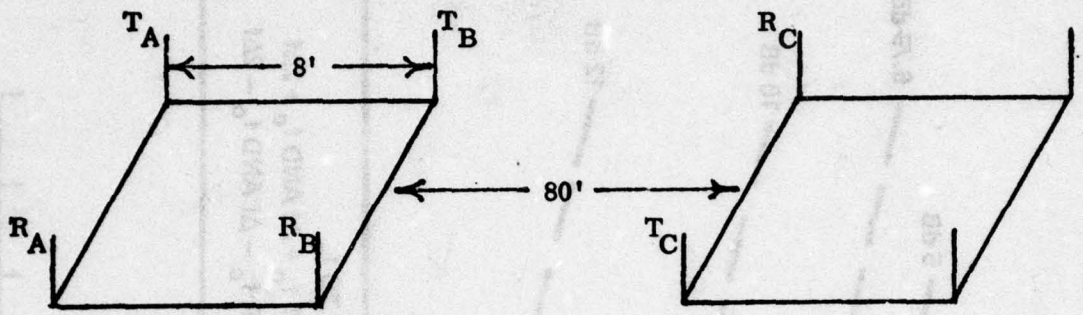


Exhibit 5-39

RECEIVER INTERMODULATION



CASE: T_A T_B R_C Low VHF BAND ΔF = 500 kHz

T_A Power Out (50 watts)	47 dbm
T_A Cable Loss	- 2 db
T_A Antenna Gain	0 db
T_A - R_C Space Loss	- 41.7 db
R_C Antenna Gain	0 db
R_C Cable Loss	- 2 db

* * *

T_A Signal into Receiver R	1.3 dbm
T_B Signal into Receiver R	1.3 dbm

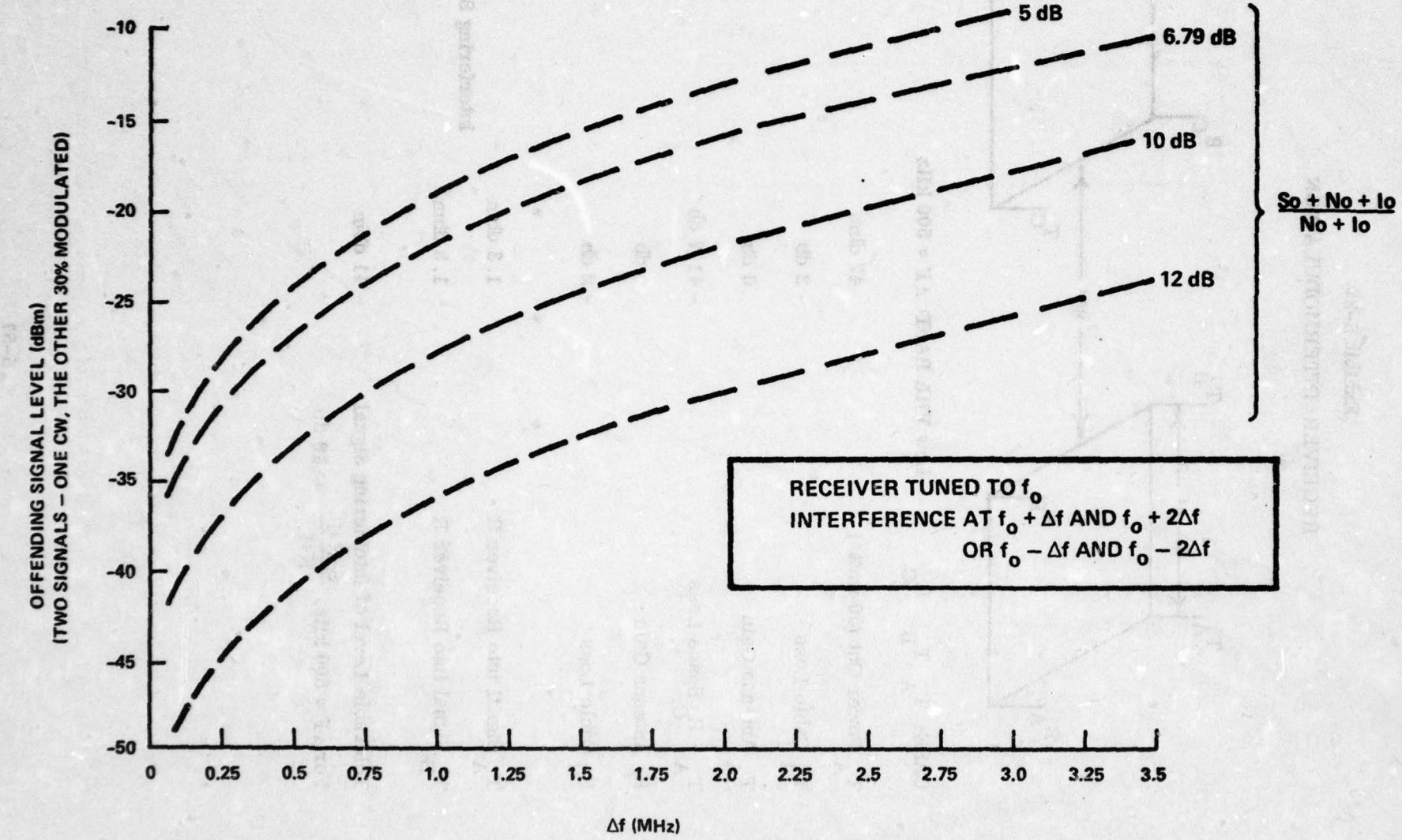
Interfering Signal Levels

Tolerable Level of Interfering Signal - 41 dbm

For ΔF = 500 kHz $\frac{S+N+I}{N+I}$ = 10 db

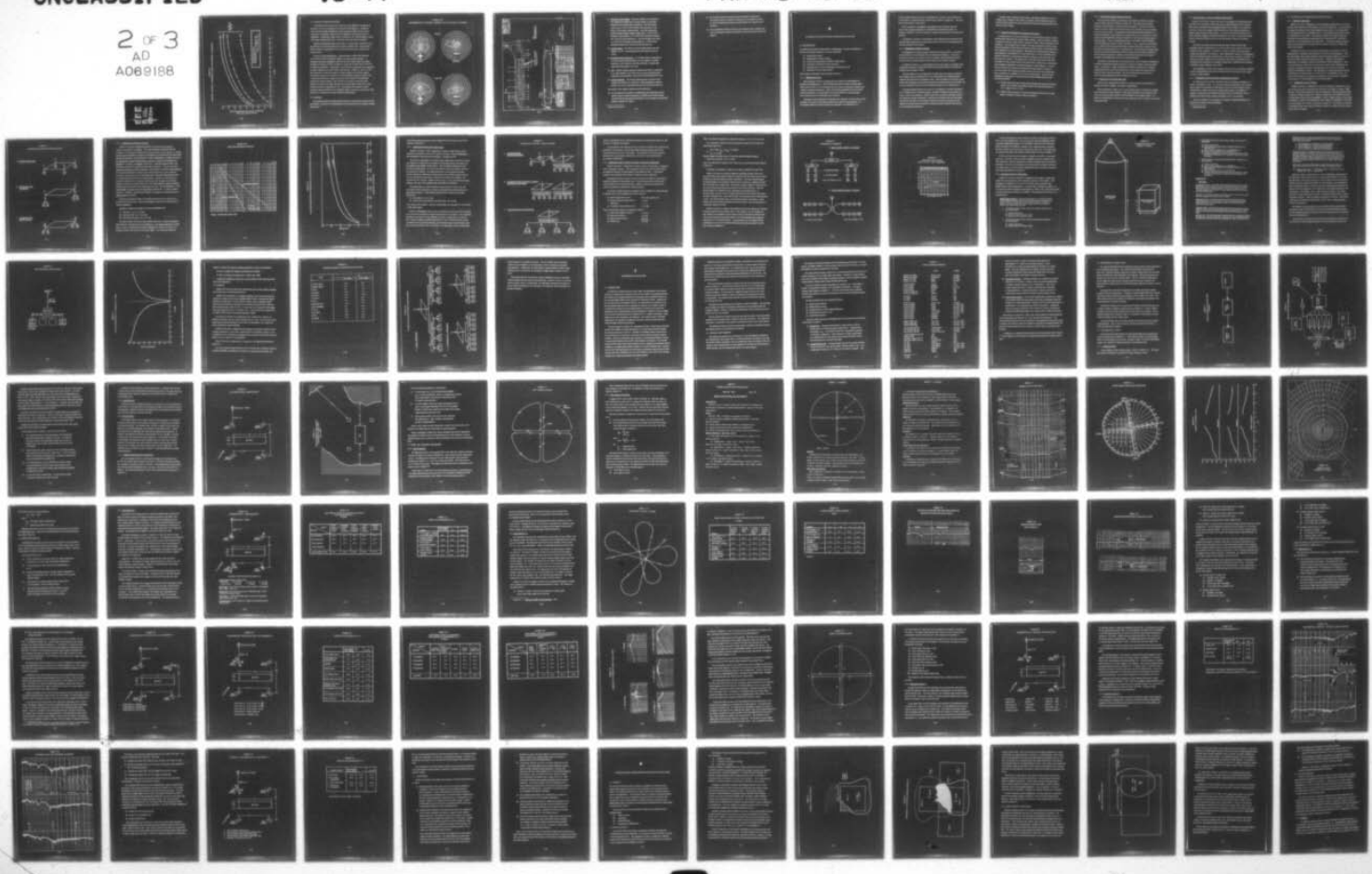
Exhibit 5-40

RECEIVER AN/GRR-23 INTERMODULATION CHARACTERISTIC (ESTIMATED)



AD-A069 188 VERVE RESEARCH CORP ROCKVILLE MD F/G 17/2.1
ADVANCED COMMUNICATIONS SYSTEMS SUPPORT. AIR/GROUND RADIO ANTEN--ETC(U)
JAN 78 J HANSEN, A WEBSTER DOT-FA75WAI-570
UNCLASSIFIED VS-44 FAA-RD-78-11 NL

2 OF 3
AD
A069188



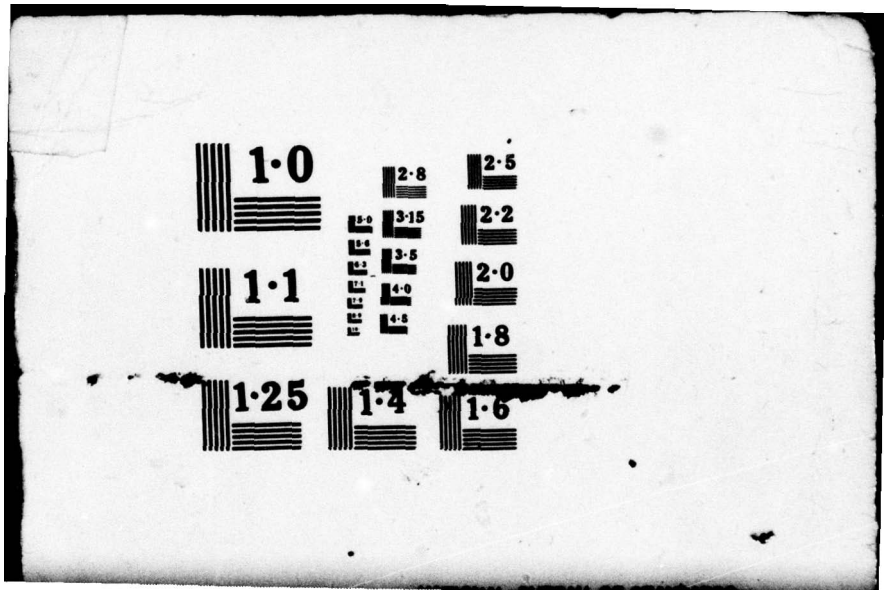
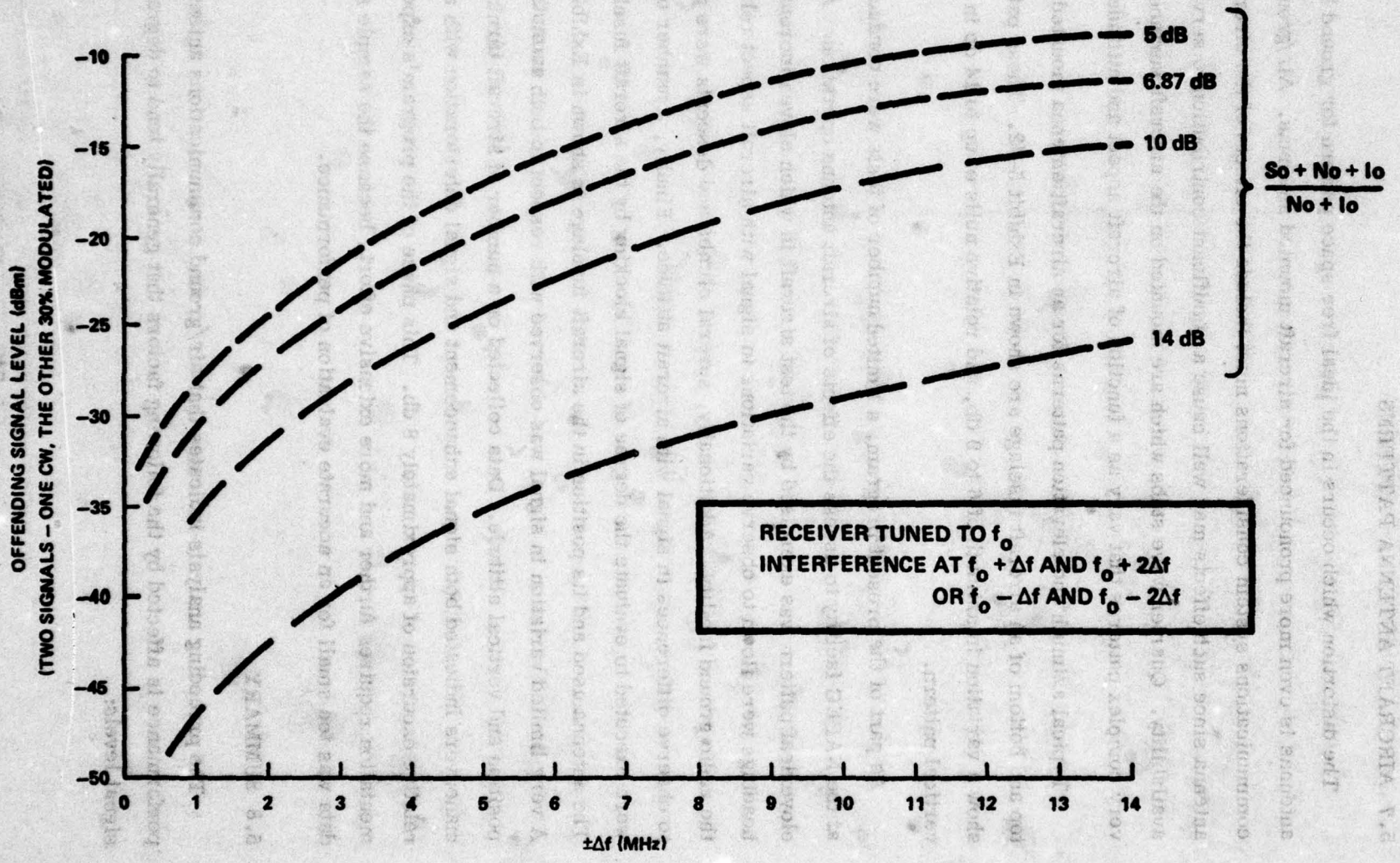

1·0
1·1
1·25
2·8
3·15
3·5
4·0
4·5
2·5
2·2
2·0
1·8
1·4
1·6

Exhibit 5-41

RECEIVER AN/GRR-24 INTERMODULATION CHARACTERISTIC (ESTIMATED)



5.7 AIRCRAFT ANTENNA PATTERNS

The distortion which occurs in the ideal free space pattern for ground based antennas is even more pronounced for aircraft mounted antennas. Air/ground communications system considerations must include the effects of the aircraft antenna since such effects may well cause a significant contribution to service availability. Quarter wave stubs which are mounted on the aircraft surface, create very complex patterns that vary as a function of aircraft aspect and attitude.

Typical azimuth and elevation patterns for an aircraft antenna mounted on the top and bottom of an aircraft fuselage are shown in Exhibit 5-42. These patterns show a variation in azimuth of 6 to 9 db, and relative nulls of up to 14 db in the vertical pattern.

As part of the present program, a limited number of tests were conducted at the NAFEC facility to assess the effects of aircraft antenna operation. A cloverleaf pattern was exercised by the test aircraft in which eleven incremental headings were flown to observe variations in signal with aircraft aspect relative to the radio ground facility. Additionally, several climbs and descents were performed to observe differences in signal with aircraft attitude. Finally, a number of turns were executed to evaluate the degree of signal blocking by the aircraft fuselage The antenna used and its position in the aircraft fuselage is shown in Exhibit 5-43. A very limited variation in signal was observed with respect to both azimuthal position and vertical attitude. Data collected on a number of aircraft turning maneuvers indicated both signal enhancement and signal deterioration with a peak relative excursion of approximately 8 db. This phase of the program's experimentation requires further and more extensive effort, because the sample size of the data was too small for an accurate evaluation of performance.

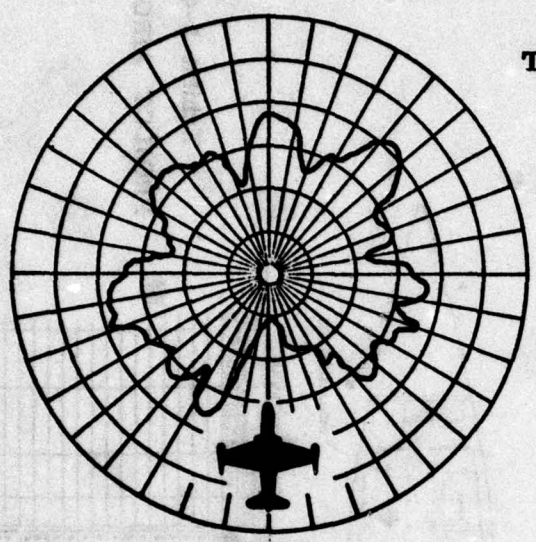
5.8 SUMMARY

The preceding analysis indicates that air/ground communications antenna systems performance is affected by the following factors that generally tend to degrade expected signal levels:

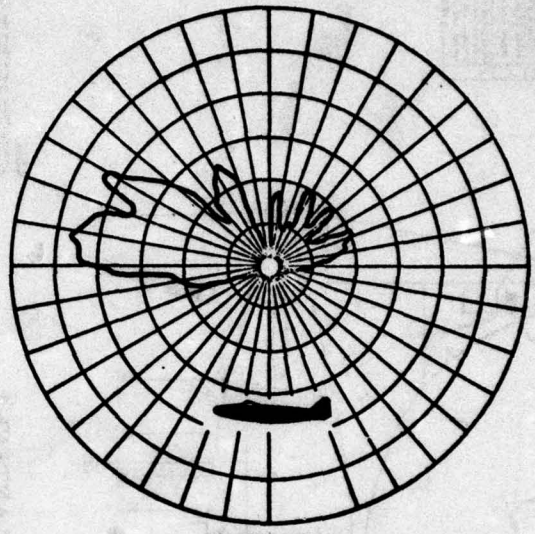
Exhibit 5-42

REPRESENTATIVE AIRCRAFT AZIMUTH AND ELEVATION PATTERNS

Topside

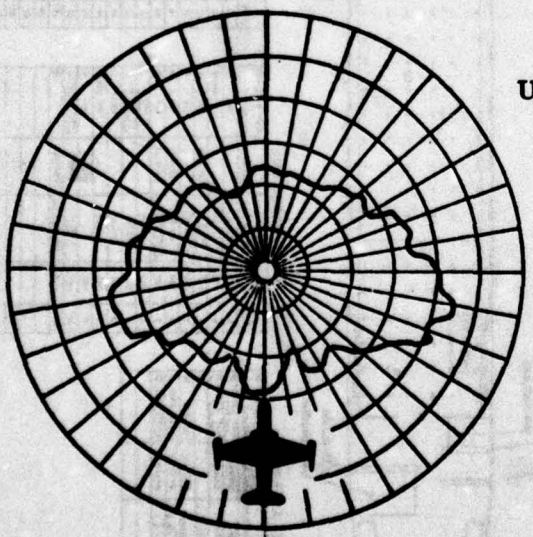


AZIMUTH

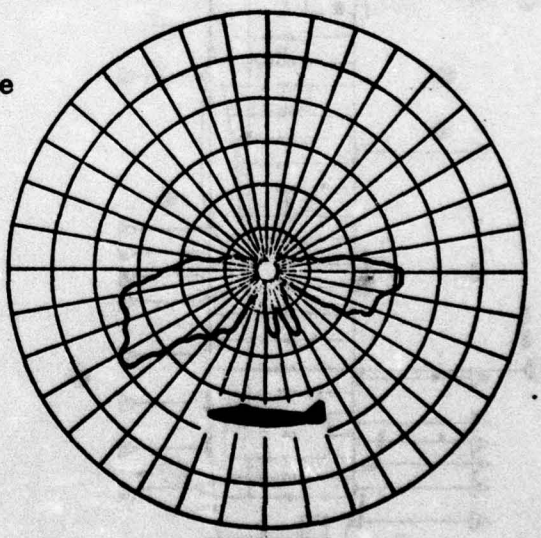


ELEVATION

Underside



AZIMUTH



ELEVATION

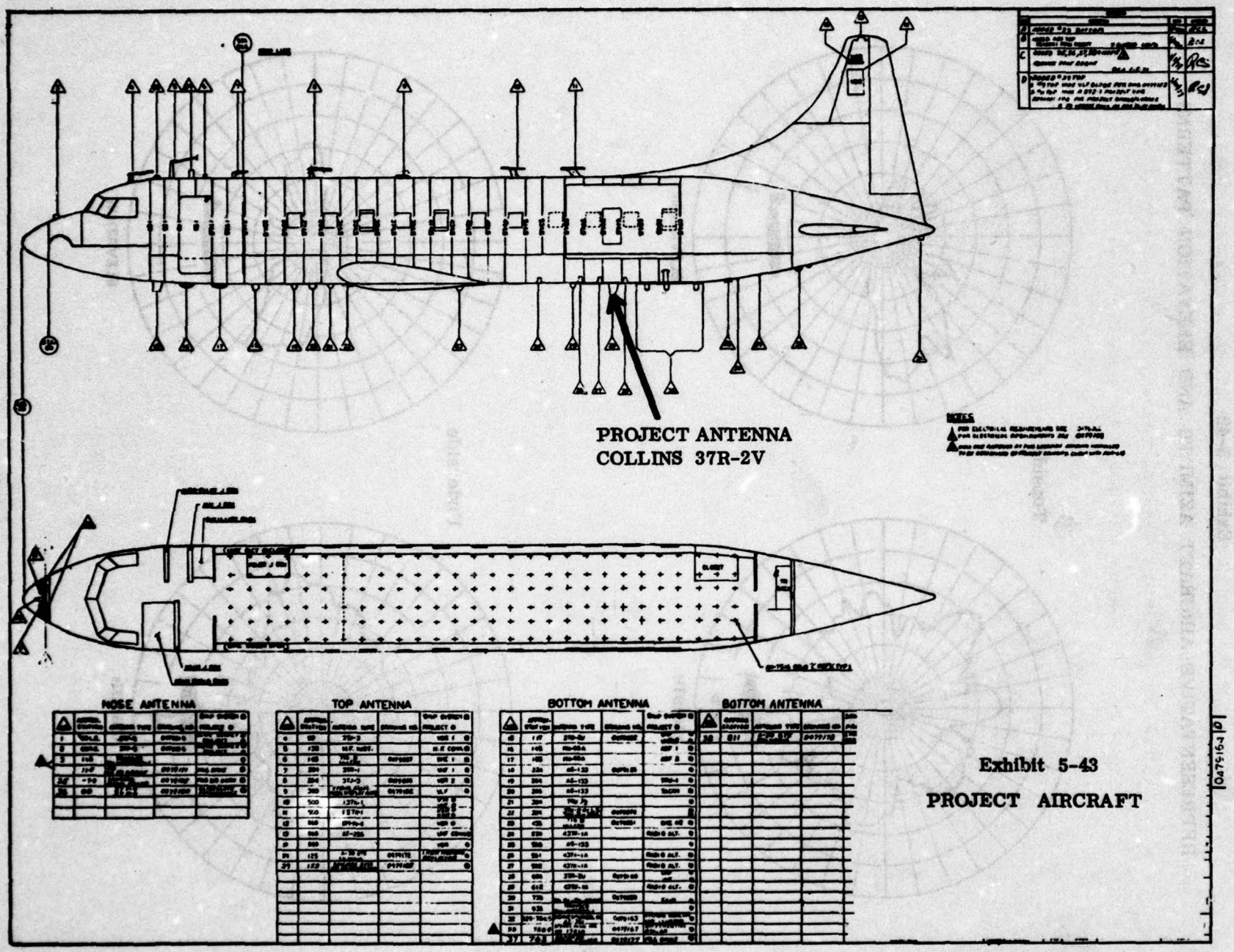


Exhibit 5-43

PROJECT AIRCRAFT

(1) Free Space Power Budget. The power budgets as calculated for VHF uplink and downlink show a modest margin for both high altitude and low altitude sector operations. The VHF margin varies from +1.0 db for HAT downlink communications to +13 db for LAT downlink communications. The UHF performance exhibits negative signal margins ranging from -0.5 db for LAT downlink communications to -8.5 db for HAT downlink operations (for 10 watt aircraft transceivers). The VHF margin varies from +1.0 db for HAT downlink communications to -8.5 db for HAT downlink operations (for 10 watt aircraft transceivers).

(2) Vertical Lobing. The effects of vertical lobing enhance the VHF signal by 0.3 to 4.5 db and degrade the UHF signal as much as -13 db.

(3) Horizontal Pattern Distortion. For multiple antenna configurations in close proximity (approximately one wave length) to mounting hardware, tower structures, and other antennas, it appears that signal nulls approaching -9 db occur.

(4) RFI. With the standard spacing of antennas and towers as employed at en route facilities, RFI in the form of receiver desensitization, transmitter intermodulation, and receiver intermodulation can occur.

(5) Aircraft Antennas. The aircraft antenna pattern variation in both azimuth and elevation can contribute a signal degradation of approximately 1 to 2 db for level flight and up to 8 db in turning maneuvers.

The results of this analysis indicate several conclusions:

(1) The available power margins as established by the transmitter powers and the ranges of expected operations, modified by the vertical lobing structure and aircraft antenna performance, will not support an air/ground channel reliability of 0.9999.*

*See FAA-RD-76-154

(2) The potential exists for minimizing horizontal pattern distortion by reducing the number of antennas, avoiding the use of metallic mounting structures and positioning antennas symmetrically with respect to tower platforms.

(3) RFI is potentially present with the en route antenna system configurations and the introduction of filters is indicated to reduce the level of interfering signals.

6

ALTERNATIVE ANTENNA SYSTEM CONFIGURATION ANALYSIS

6.1 INTRODUCTION

In considering alternative antenna system configurations, a number of guidelines, in the form of desirable objectives, have been formulated:

(1) minimization of RFI,

(2) maximization of radio coverage,

(3) provision of potential for colocation configurations,

(4) provision for multiple site space diversity,

(5) responsiveness to service availability requirements, and

(7) utilization of current physical plant

Each of these is discussed in the following subsections.

6.1.1. Minimization of RFI

The occurrence of RFI is a complex process in which it is often difficult to identify the offending source. Radio facilities personnel normally eliminate identifiable sources of RFI, but are frequently left with chronic interference problems that continue to degrade performance. Since RFI is always generated by the local radio signal environment, it is not possible to solve the problem by increasing signal power because the level of interaction also increases.

Assuming a fixed configuration of antenna tower locations, as found at the en route facilities, the amount of separation between towers cannot be easily altered. If the antenna isolation cannot be increased by separation, the alternative is to

introduce added isolation by means of signal filtering. However, the introduction of various filters or isolation devices or both exacts a penalty in signal loss. This trade-off is discussed later in this report.

RFI is created in a multisignal environment so that it will tend to become worse as more signal frequencies are added due to increased air activity, co-location of facilities, and the introduction of multiple site operations to provide space diversity.

The analysis in section 5.6 (pertaining to RFI) indicated that desensitization and intermodulation interference are potentially present in the current configurations and can cause problems if not treated.

6.1.2. Maximization of Radio Coverage

The degradation of radio coverage of idealized free space contours is caused by terrain obstacles, vertical lobing and horizontal pattern distortion. The terrain obstacles can only be overcome by the use of multiple radio facilities that provide diversity of line-of-sight conditions to fill in gaps in the required coverage.

As shown in section 5.4, vertical lobing creates serious gaps in coverage at UHF frequencies but appears to generally enhance the free space field at VHF within the required sector airspace volume.

Placing antennas at lower heights than currently used, as a means of maximizing coverage, appears impractical due to the requirements for providing adequate clearance above the site's surrounding terrain. Since the height of the antenna is fixed and the radio frequency is also fixed, the presence of vertical lobing is unavoidable, but it can be controlled by space diversity obtained through the use of multiple sites.

Horizontal pattern distortion can occur as a consequence of multiple reflections and re-radiation of the transmitted signal. Isolation of antennas from parasitic elements, such as other antennas, metallic structures, and nearby reflecting surfaces, can reduce the amount of distortion. Symmetry of the antenna with its surrounding environment will tend to reduce signal variations in the horizontal plane since the shifting of vertical lobes as a function of azimuth (around the antenna) will show up as horizontal pattern distortion.

It appears that an approach that provides a gap filling capability by the use of multiple sites, reduction in the number of antennas, and increasing the degree of isolation of the antenna from nearby metallic elements and reflecting surfaces will improve radio coverage.

6.1.3. Provision of Potential for Colocation Configurations

In simple terms, it is most cost-effective to use the minimum number of radio facilities that will provide the required radio coverage. Radio coverage is required to support en route air traffic control, terminal air traffic control; and flight service operations. Line-of-sight radio coverage to service the airspace for these various functions should be provided from the smallest possible number of sites with colocation of functions at common facilities. Additionally, the requirement that exists, in many instances, of providing two or more radio sites to cover one airspace sector should be satisfied by using primary locations as backup or space diversity locations wherever possible. The engineering of colocated radio facilities will add to the number of radio channels that must be supported at a single site, so that proper space planning is important to increase the number of radio channels. As an example, a current ATC terminal communications facility located at an airport may also provide radio channels for flight services; and it may also provide gap-filler coverage for low altitude ATC en route communications. The key to such configuration engineering is to provide universal radio facilities that have the following capabilities:

(1) Primary fixed tuned radio equipment and antennas that support the primary mission of the facility in providing assigned radio channel functions for ATC or flight services or both.

(2) Tunable radio transceivers that can be selected and tuned for use as gap fillers or backup to adjacent radio site locations.

6.1.4. Potential for Multiple Site Space Diversity

There are many situations, particularly at low altitudes, where the required radio coverage cannot be provided by a single site. This may be due to terrain shielding, vertical lobing, or horizontal pattern distortion. The use of a second location is a form of space diversity that increases the resultant service availability over the airspace volume. The experience with the BUEC (Backup Emergency Communications) facilities in the Oakland area indicate that they are employed, to a great extent, to provide gap filler coverage to primary en route sites that possess gaps in radio coverage. The use of tunable transceivers, as in BUEC, allows flexibility in shared operations among air traffic controllers. Thus, a particular radio facility (e.g., a BUEC location) may provide backup coverage with tunable transceivers for this function allowing shared use on a priority basis. This approach is distinguishable from the current BUEC philosophy in that the space diversity of backup capability is located, whenever possible, at primary radio facilities that possess the required location for providing backup coverage for adjacent facilities.

The impact of this approach on the antenna system is that it becomes advantageous to utilize omnidirectional antennas that may be shared by airspace coverage requirements. For example, a single omnidirectional antenna connected to an N-channel multicoupler may be used for providing primary radio channel coverage as well as backup or space diversity coverage. The use of directional antennas would be limited to unique applications where no alternative exists.

6.1.5 Utilization of Current Physical Plant

The FAA has a considerable investment in current en route radio facilities including real estate, buildings, and antenna configurations.

Often the placement scheme in the current antenna layouts is bounded by available space and cannot be easily extended. Under these conditions, the assumption is that the current physical plant facilities will be employed to the maximum extent. Any addition of radio facilities would result in new construction costs as well as an increased maintenance load.

6.1.6 Responsiveness to Service Availability Requirements

Chapter 2 of the Phase I report* shows that the attainment of a 0.9999 availability of service for the air/ground radio system was a realistic objective for all segments of the system, except the radio propagation channel whose reliability was estimated to be 0.90. There are two factors which increase the radio channel reliability (excluding a large increase of signal power): 1) the use of time diversity where the air traffic controller engages in repeated transmissions, and 2) the use of space diversity where the controller utilizes more than one radio facility to obtain solid reliable coverage.

The study and analysis prepared during this effort confirm that the radio propagation channel reliability does not have the signal margin needed to achieve the required systems reliability. Therefore, in order to respond to the requirement, multiple site operations are necessary. Such configurations require the introduction of selective switching and radio tuning similar to that provided, at present, by BUEC. As shown in the Phase I study,* the use of switches in the system can degrade service availability unless employed in a redundant configuration consistent with the expected availability of other segments of the system.

The availability of service of the antenna system must also be carefully considered in view of the application of common use devices such as multicouplers that support a number of radio channels.

6.1.7. Compatibility with Cost-Effective Maintenance Procedures

An urgent goal of the Airways Facilities Service is to achieve a limiting or reduction of maintenance costs. For air/ground radio communications, this objective will be attained by automation of maintenance services at remote facilities so that site technician visitation rates may be substantially reduced. The addition of complex or physically large antennas and devices such as multicouplers must be limited to the extent that the expected maintenance load is not increased.

The above guidelines are employed in the analysis of potential alternate configurations for antenna systems that follow.

---

*FAA-RD-76-154

6.2 ALTERNATIVE ANTENNA SYSTEMS CONFIGURATION

6.2.1. Standard Configuration

Exhibit 6-1A shows a standard en route radio facility configuration for one tower with one radio channel (one UHF frequency and one VHF frequency). Four such towers will support a maximum of four radio channels (one per tower). This configuration as now employed by FAA is straightforward sir e each transmitter and each receiver is connected to its own antenna. The antennas employed are circularly polarized swastikas for transmitting and coaxial dipoles for receiving at VHF, and discone antennas for both transitting and receiving at UHF. Various gain antennas (such as yagis) have been employed at selected sites to increase the signal for specific portions of the airspace.

As noted in section 5.6, the standard configuration is susceptible to receiver desensitization, transmitter intermodulation, and receiver intermodulation. Also, the four antennas and mounting hardware sharing the antenna platform may also exhibit some degree of horizontal pattern distortion. Without a comprehensive field survey, it is difficult to assess the performance of this configuration. Many air/ground facilities exhibit gaps in the desired coverage, but the deficiencies may be due to a combination of factors including items such as terrain shadowing, which is very difficult to remedy. The introduction of omnidirectional gain antennas would improve the signal margin, but would increase susceptibility to RFI. The primary disadvantage of this standard arrangement is the upper bound established for the number of radio channels that can be accommodated.

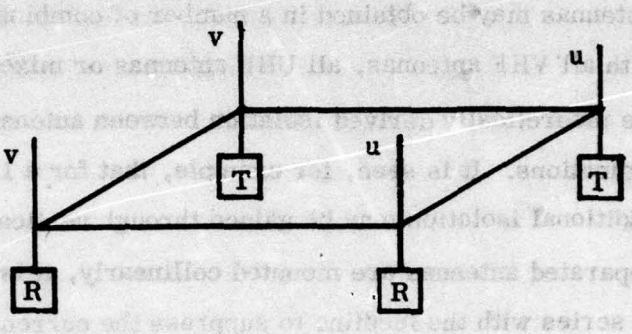
6.2.2. Configuration with TR Switches

Exhibit 6-1B shows a configuration in which each antenna is connected to a transmit-receive (TR) switch which allows the transmitter and receiver to share a single antenna. The principal advantage of such an arrangement is that the resulting number of antennas is halved relative to the standard configuration, thus doubling the number of radio channels that can be accommodated. However, adding antennas to the arrangement shown, to realize a full complement of four antennas on the platform, will result in an unacceptable level of RFI as discussed in section 5.6. The reduction of this RFI to acceptable levels would require the addition of filters or isolators or both to attenuate the undesired signals.

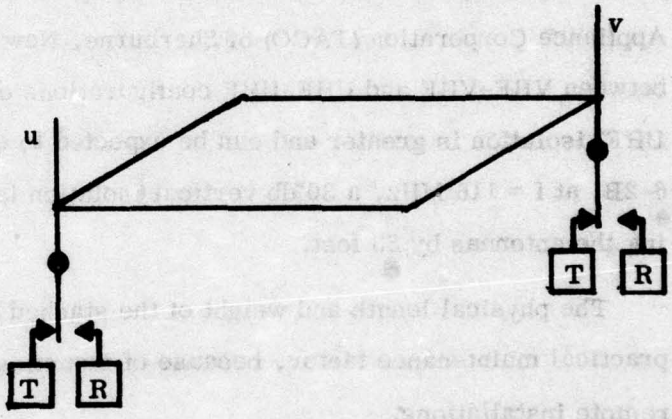
Exhibit 6-1

ALTERNATIVE ANTENNA CONFIGURATIONS

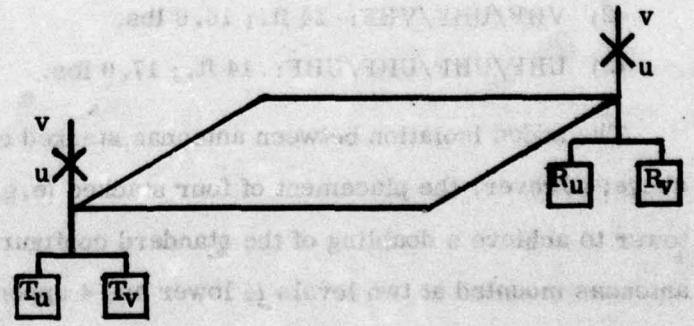
A. Standard Configuration



B. Configuration With TR Switches



C. Configuration With Stacked Antennas



6.2.3. Configuration with Stacked Antennas

Exhibit 6-1C shows a configuration wherein two separate and independent antennas are stacked in one radome. The main advantage of employing this type of antenna is the increased isolation between antennas with vertical separation. Stacked antennas may be obtained in a number of combinations involving double and triple stacks with all VHF antennas, all UHF antennas or mixed configurations. Exhibit 6-2A shows the theoretically derived isolation between antennas in collinear and broadside configurations. It is seen, for example, that for a 1 λ separation approximately 10 db additional isolation may be gained through vertical separation. When the vertically separated antennas are mounted collinearly, it is necessary to provide a high impedance in series with the feedline to suppress the current induced on the outer conductor. An isolator consisting of several cable chokes and a broad band compensating circuit is normally placed between the two vertical dipoles. Isolation measurements performed by manufacturers of collinear stacked arrays (for example, The Technical Appliance Corporation (TACO) of Sherburne, New York) indicate a minimum isolation between VHF-VHF and UHF-UHF configurations of 30 db. The cross band (i.e., VHF-UHF) isolation is greater and can be expected to exceed 40 db. As noted in Exhibit 6-2B, at f = 116 MHz, a 30 db vertical isolation is equivalent to horizontally separating the antennas by 33 feet.

The physical length and weight of the stacked antennas must be considered as a practical maintenance factor, because of mounting and otherwise moving antennas at remote installations.

Examples of lengths and weights for various combinations are:

(1) VHF/VHF: 12.5 ft.; 12.5 lbs.

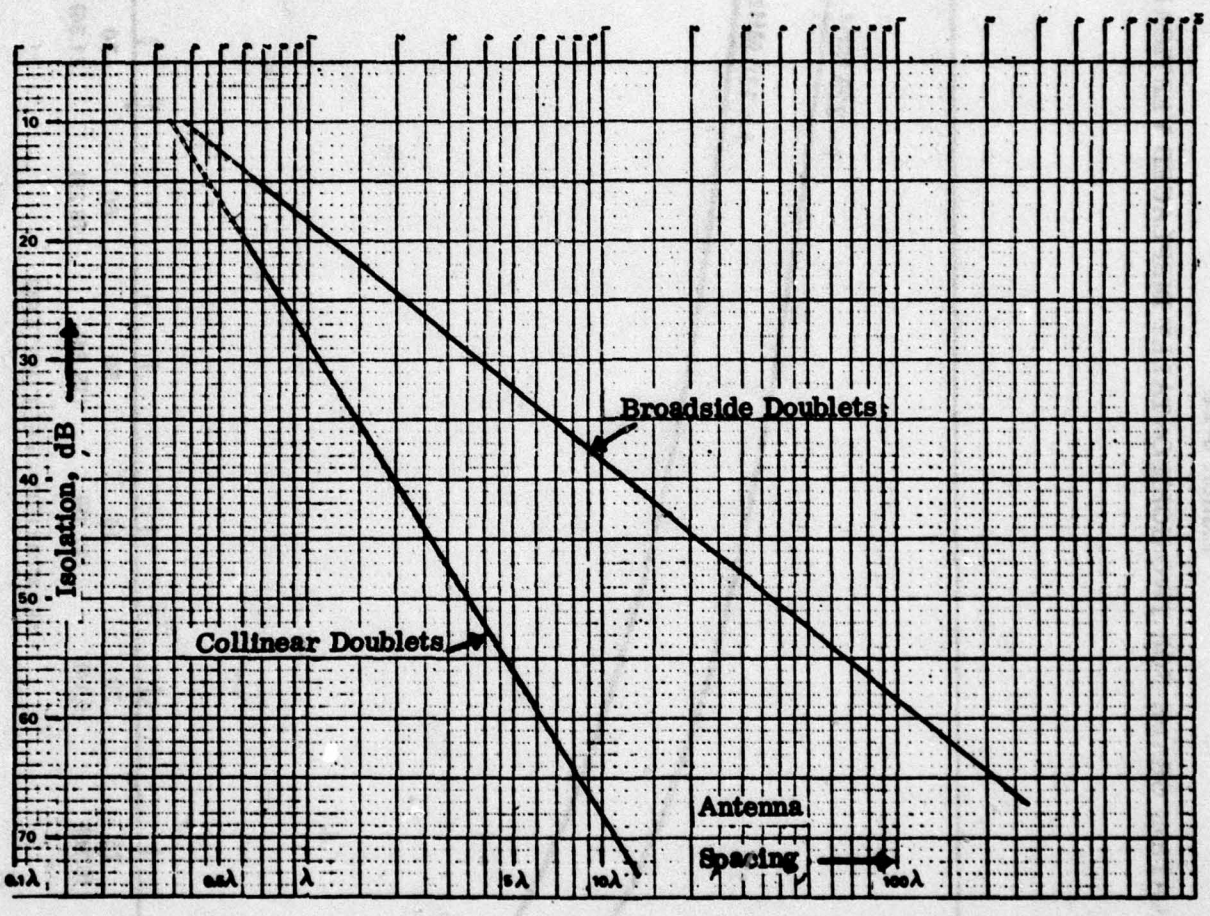
(2) VHF/UHF/VHF: 14 ft.; 16.0 lbs.

(3) UHF/UHF/UHF/UHF: 14 ft.; 17.0 lbs.

The added isolation between antennas stacked collinearly is gained as explained above; however, the placement of four stacked (e.g., two dipole) antennas on a single tower to achieve a doubling of the standard configuration, results in a cluster of 8 antennas mounted at two levels (4 lower and 4 upper). The interaction among the

Exhibit 6-2A

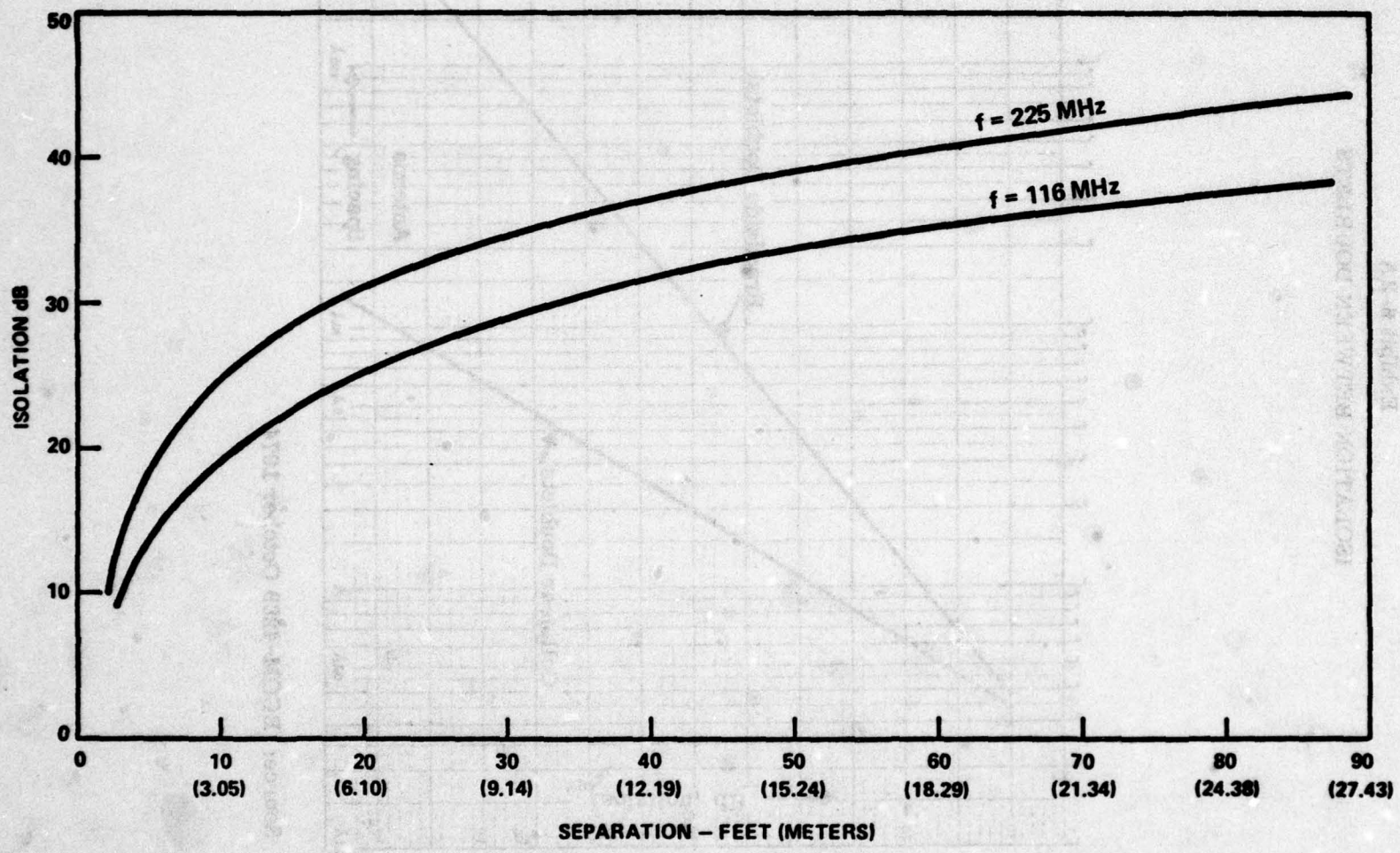
ISOLATION BETWEEN DOUBLETS



Source: ECOM-4269 October 1974

Exhibit 6-2B

ISOLATION GRAPH FOR TWO HORIZONTALLY DISPLACED VERTICAL DIPOLES



horizontally separated antennas of this configuration will be similar to that of the standard configuration.

6.2.4. Configuration with Receiver Multicoupler

Exhibit 6-3A shows a tower configuration in which a single antenna, center mounted on the platform, serves four receivers through a receiver multicoupler. The transmitters shown are each connected to a separate antenna.

The receiver multicoupler is an active device comprising a wide band RF amplifier followed by a distribution and isolation network which passes any signal from the antenna to the multiple receiver ports. Since no channel selectivity is exercised by the multicoupler, the receiver preselector acts as the selective device for the separation of signals. The signal distribution is accomplished with power dividers followed by attenuators to achieve port to port isolation among receivers. The loss through the multicoupler is balanced by the gain of the amplifier. By appropriate power division, multiple receivers (e.g., 2, 4, 8, 16, 32) can be accommodated. The gain of the amplifier limits the number of receivers.

The multicoupler is inserted between the antenna and the receiver; so, the noise figure of the multicoupler as well as its intermodulation characteristics are important parameters. Representative parameters for available multicoupler devices are:

(1) Noise figure: 5.5 to 12 db

(2) Third order intermodulation intercept point: 20 to 36 dbm

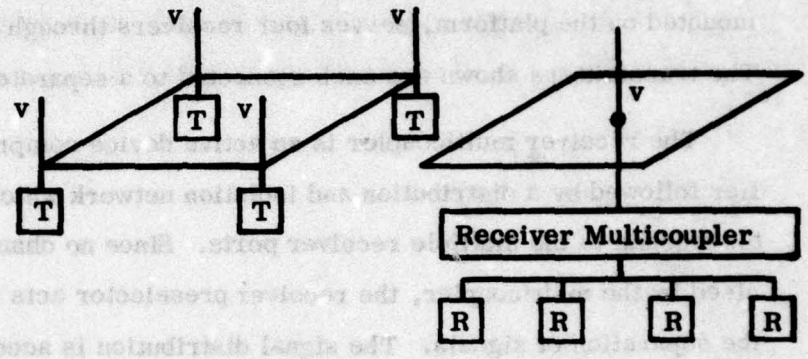
At the output of the amplifier, the third order products are nominally 75 to 80 db below a 0 dbm output signal.

Receiver multicouplers with as many as 20 ports for receivers have been operated in air terminal environments to support multichannel FAA operations. The outstanding advantage of such devices is the capability to operate a large number of receivers with a single broadband, omnidirectional antenna, with no additional system losses. As applied to the en route environment, one VHF antenna plus one UHF antenna could serve all VHF and UHF receivers connected to the appropriate receiver multicoupler.

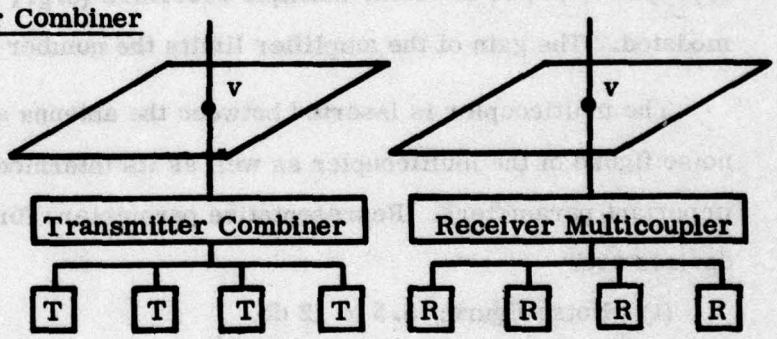
Exhibit 6-3

ALTERNATIVE ANTENNA CONFIGURATIONS

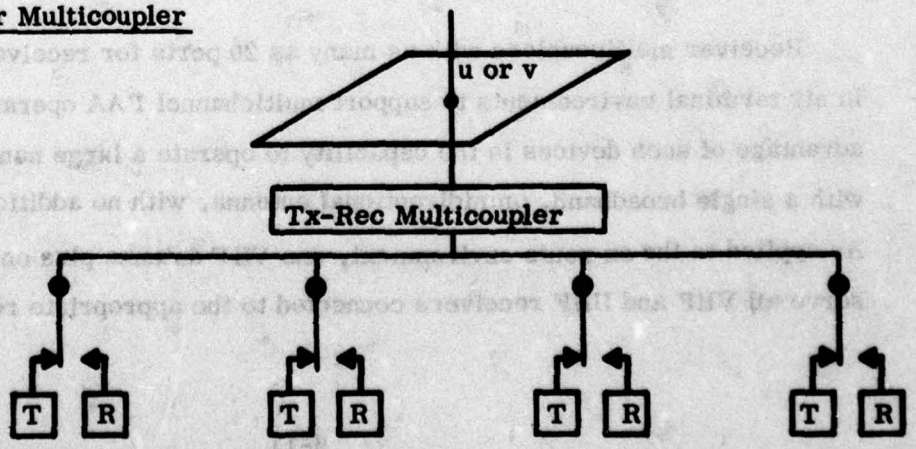
A. Configuration With Receiver Multicoupler



B. Configuration With Transmitter Combiner and Receiver Multicoupler



C. Transmitter-Receiver Multicoupler



Such an arrangement allows a substantial potential for increasing the number of radio channels at a specific site location.

The transmitters with separate antennas, as shown in Exhibit 6-3A, will show the potential for the generation of transmitter intermodulation products that will not be attenuated by the receiver multicoupler. The conditions for receiver desensitization and for intermodulation interference are similar to those discussed for the standard configuration.

6.2.5 Configuration with Transmitter Combiner and Receiver Multicoupler

Exhibit 6-3B shows a configuration in which a receiver multicoupler is employed with a transmitter combiner. The arrangement shown is for VHF and would require an additional combiner and multicoupler for the addition of UHF. A substantial capacity to accommodate radio channels is inherent in this configuration.

Transmitter combiners assume a number of forms that relate to the frequency separation available at the particular site. A basic building block used for transmitter combiners is the tuned cavity filter, which is used to provide isolation between the transmitters connected to a common antenna.

The required isolation between transmitters may be obtained by starting with the acceptable level of intermodulation into a given receiver:

(1) Desired signal power level =	-103.4 dbm (Exhibit 5-5)
(2) Desired/undesired signal ration =	14.0 db
which gives	
(3) Acceptable intermodulation level =	-117.4 dbm

Then, the associated losses are calculated as follows:

(1) Cable losses (XMTR + RCVR) =	-4.0 db
(2) Space loss (80 feet) =	-41.7 db
(3) Signal conversion loss =	-31.0 db
(4) Total losses	-76.7 db

Thus, the required transmitter to transmitter isolation = 117.4 - 76.7 = 40.7 db

FCC regulations require that the intermodulation product level be below the main carrier power by:

$$43 + 10 \log P_{avg.} \quad (P_{avg.} = 50 \text{ watts})$$

or

$$43 + 17 = 60 \text{ db.}$$

With the stated conversion loss of -31 db, the required isolation becomes:

Transmitter Isolation: 60 -31 = 29 db.

Thus, the first derived isolation of 40.7 db is more conservative than that required by the FCC.

Two forms of transmitter combiners are shown in Exhibits 6-4A and 6-4B.

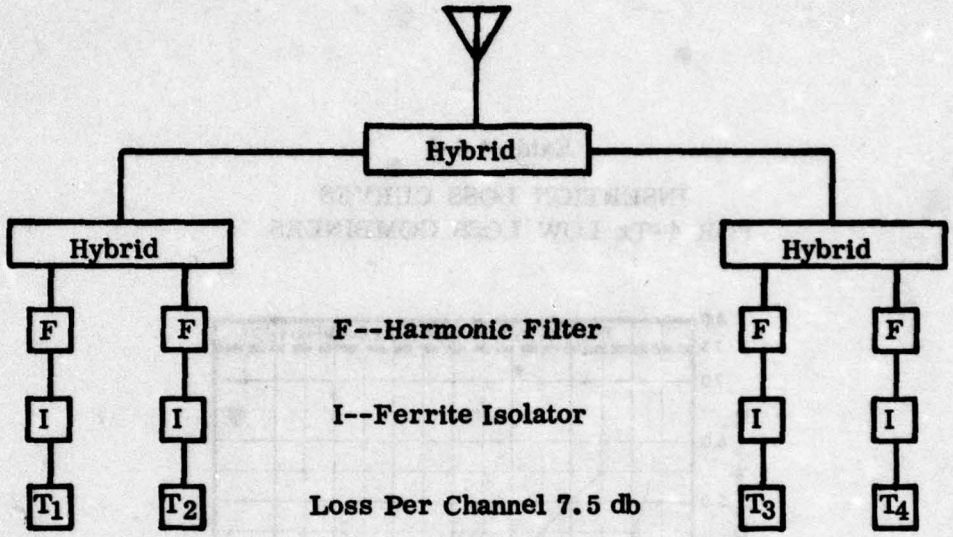
Exhibit 6-4A shows a commonly employed transmitter combiner that uses a four port ferrite device (hybrid coupler) in conjuction with three port ferrite devices (isolators) to provide isolation between transmitters. The major disadvantage of the hybrid coupler is its minimum insertion loss of 3 db due to a splitting of power into the antenna and a dummy load. The isolator typically exhibits an insertion loss of 0.5 db in the forward direction and 25 db in the reverse direction. Since the ferrite isolator is a nonlinear device, harmonics may be generated; so, a harmonic filter or tuned cavity is usually inserted between the isolator and antenna as shown in Exhibit 6-4A. The harmonic filter has an insertion loss of approximately 0.2 db. The hybrid coupler gives a 40 db isolation between transmitters. When added to the 25 db isolation provided by the ferrite isolator, the total transmitter to transmitter isolation is 65 db.

Exhibit 6-4B shows a combiner that exhibits lower loss per channel by replacing the lossy hybrid with tuned cavities and an n-way junction. The two isolators in each channel arm contribute 50 db of isolation and the off-frequency characteristic of the tuned cavities will contribute another 10 to 20 db depending upon frequency separation, for a total of 60 to 70 db. A representative loss per channel for this configuration is 2.5 db at 150 MHz for frequency separations of greater than 200 kHz as shown in Exhibit 6-5.

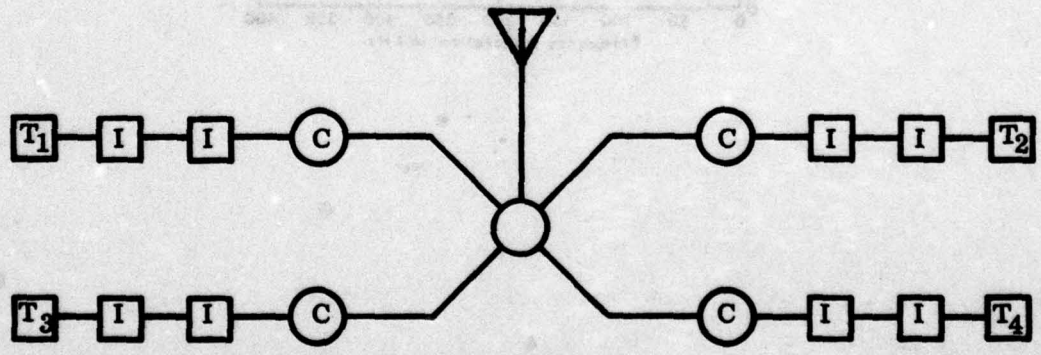
Exhibit 6-4

TRANSMITTER COMBINERS

A. Hybrid Coupler Combiner (4 Channel)



B. N-Way Junction Combiner (4 Channel)

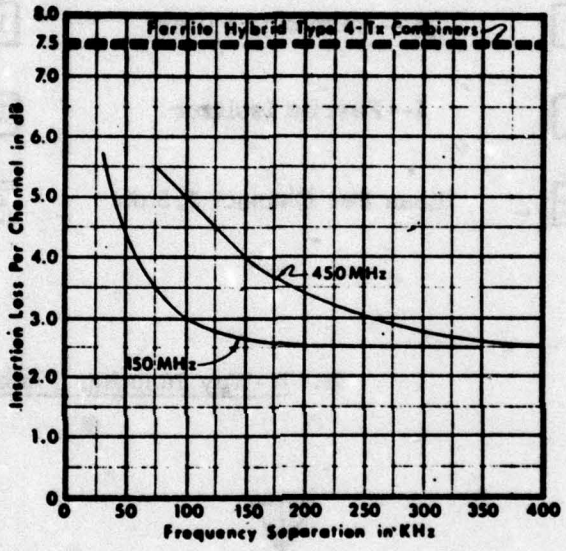


C--Tuned Cavity Filter

Loss Per Channel 2.5 db

Exhibit 6-5

INSERTION LOSS CURVES FOR 4-Tx LOW LOSS COMBINERS



A major disadvantage of using transmitter combiners with coaxial cavities at VHF is the large physical size. The use of helical resonators that demonstrate comparable performance allows a very substantial reduction in size and weight. Helical resonators are similar to a quarter wave coaxial resonator except that the inner conductor is in the form of a helix rather than a rod. The relative size of a coaxial cavity filter and a helical resonator filter are shown in Exhibit 6-6.

If the insertion loss of the transmitter combiner can be held to a reasonable value (e.g., less than 2.5 db), and with a practical size device available at the VHF frequencies, then the configuration as shown in Exhibit 6-2B is an attractive alternative. The use of the combiner not only accomodates multiple transmitters on a single antenna, but also provides additional filtering to minimize transmitter noise and intermodulation interference.

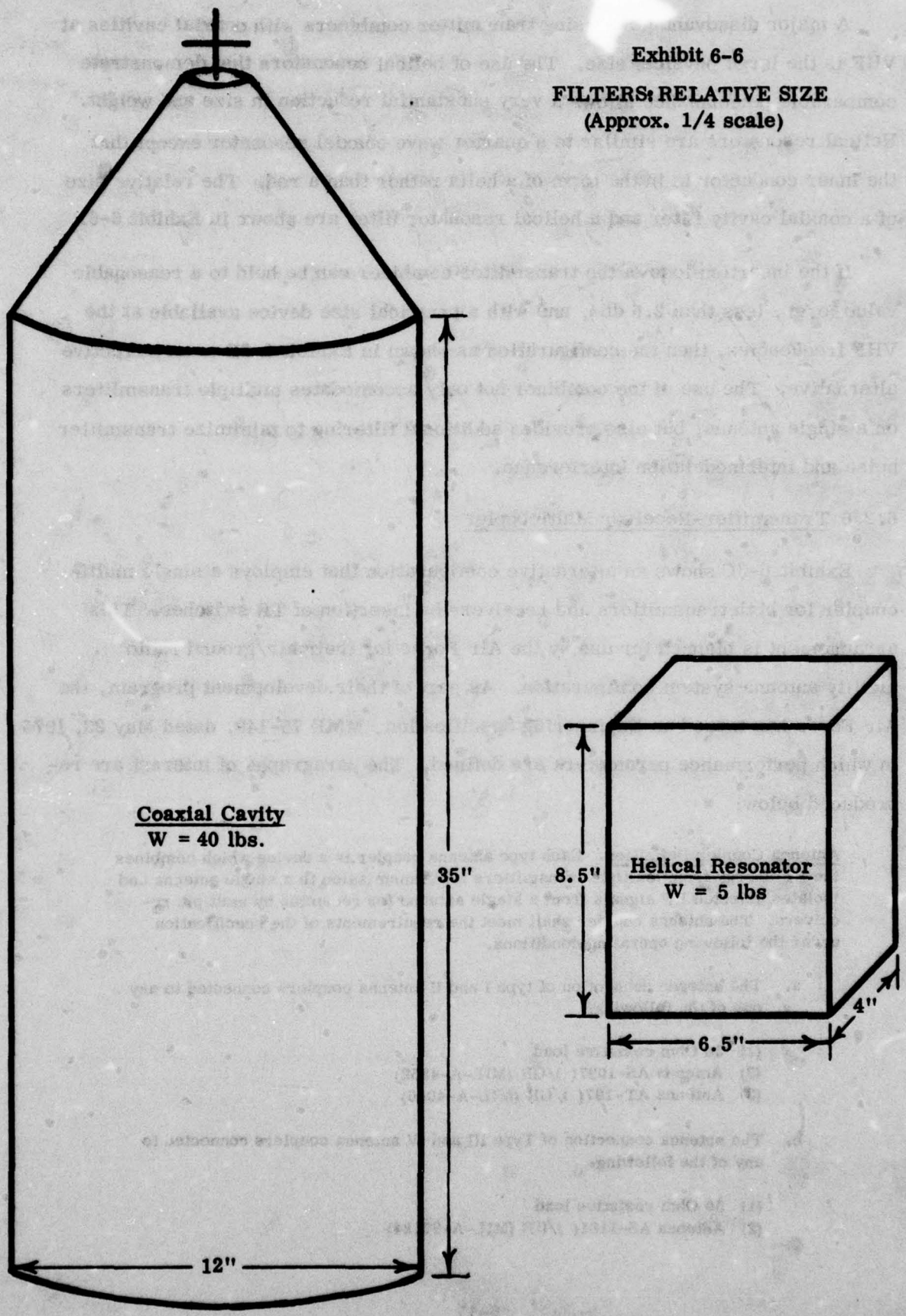
6.2.6 Transmitter-Receiver Multicoupler

Exhibit 6-3C shows an alternative configuration that employs a single multicoupler for both transmitters and receivers by insertion of TR switches. This arrangement is planned for use by the Air Force for their air/ground radio facility antenna system configuration. As part of their development program, the Air Force has issued an Engineering Specification, *MME 75-149, dated May 23, 1975* in which performance parameters are defined. The paragraphs of interest are reproduced below:

> Antenna Coupler Definition. Each type antenna coupler is a device which combines the RF energy from multiple transmitters for transmission to a single antenna and isolates selected RF signals from a single antenna for reception by multiple receivers. The antenna coupler shall meet the requirements of the specification under the following operating conditions.
>
> a. The antenna connection of type I and II antenna couplers connected to any one of the following:
>
> (1) 50 Ohm resistive load
> (2) Antenna AS-1097( )/GR (MIL-A-4852)
> (3) Antenna AT-197( )/GR (MIL-A-4946)
>
> b. The antenna connection of Type III and IV antenna couplers connected to any of the following:
>
> (1) 50 Ohm resistive load
> (2) Antenna AS-1181( )/UR (MIL-A-27124)

Exhibit 6-6

FILTERS: RELATIVE SIZE
(Approx. 1/4 scale)



c. Each equipment port of type I and II antenna couplers connected to one of the following:

(1) 50 Ohm resistive load
(2) Radio transmitter AN/GRT-22 and T-1109/GRC-22 Exciter (T.O. 31R2-2GRT-102)
(3) Radio transceiver AN/GRC-171 (T.O. 31R2-2GRC-171-2)
(4) Radio receiver AN/GRR-24 (T.O. 31R2-2GRT-112)
(5) A coaxial relay NSN 5820-00-733-7717 which is connected as a transmit/receive switch between the T-1109/GRT-22 and AN/GRR-24, and the coupler.

d. Each equipment port of Type III and IV antenna couplers connected to any of the following:

(1) 50 Ohm resistive load
(2) Radio receiver AN/GRR-23 (T.O. 31R2-2GRR-112)
(3) Radio transmitter AN/GRT-21 and T-1108/GRT-21 Exciter (T.O. 31R2-2GRT-102)
(4) Radio transceiver RT-723 (T.O. 31R2-2GR-1042)
(5) A coaxial relay NSN 5820-00-733-7717 which is connected as a transmit/receive switch between T-1109/GRT-22 and AN/GRR-24, and the coupler.

Characteristics

Performance

Radio frequency power. The antenna coupler shall satisfy the requirements of this specification for radio frequency (r-f) carrier power levels between 5 watts modulated 95 percent with a 1 kHz tone applied to one of the four equipment ports and 100 watts modulated 95 percent with a 1 kHz tone applied to each of the four equipment ports simultaneously.

Impedance. The impedance exhibited by the antenna coupler to the antenna terminal and to each equipment port shall be 50 ohms resistive.

Standing Wave Ratio. The voltage standing wave ratio (VSWR) exhibited by the antenna coupler to the antenna terminal and to each of the equipment ports shall not be greater than 2.0 to 1 with respect to 50 ohms over the entire frequency range of the antenna coupler.

Frequency Ranges. Each channel of each type antenna coupler shall be continuously tunable over the frequency range specified in Table I of this specification. A minimum of 2.5 percent frequency overlap shall be provided at each end of the tuning range.

Insertion Loss. The on-frequency [sic] insertion loss between any equipment port and the antenna terminal shall be less than 1.8 decibels (db). The on-frequency insertion loss between the antenna terminal and any equipment port shall be less than 1.8 d.b.

Off-channel rejection. Minimum attenuation between the antenna port and any equipment port at any inband frequency with all ports correctly terminated in 50 ohm resistive loads shall be:

a. 3 db at frequencies ± 0.0714% from the tuned frequency.
b. 20 db at frequencies ± 0.333% from the tuned frequency.
c. 40 db at frequencies ± 1.0% from the tuned frequency.
d. 60 db at frequencies ± 3.33% from the tuned frequency.

Port-to-port isolation. Attenuation between any two equipment ports tuned to frequencies separated by not less than 5 MHz and not more than 10 MHz for Type I and Type II couplers and by not less than 3 MHz and not more than 6 MHz for Type III and Type IV couplers shall be a minimum of 50 db. Attenuation between any two equipment ports tuned to frequencies separated by not less than 10 MHz for Type I and Type II couplers and 6 MHz for Type III and Type IV couplers shall be a minimum of 60 db.

Service Life. The antenna coupler shall be designed and constructed with a minimum service life of 10 years to start after a minimum storage life of 2 years.

Note: Antenna Coupler Type I - 2 channel UHF, Type II - 4 channel UHF, Type III 2 channel VHF, Type IV - 4 channel VHF.

Exhibit 6-7 shows a representative Air Force configuration employing a CU-547 multicoupler whose characteristics are illustrated in Exhibit 6-8. For the example shown, the frequency separation is wide enough to avoid receiver desensitization since the coupler will provide 100 db of attenuation to the transmitted signal reaching the receiver. However, for closer spacing among channels as is common with FAA assignments, this configuration would exhibit potential for desensitization. For example, with a 1 MHz frequency separation, the coupler attenuation is about 28 db which results in a transmitted signal level of + 19 dbm entering the receiver. Since at a frequency separation of 1 MHz a -8 dbm interfering signal will degrade the signal/noise ratio by 2 db, + 19 dbm will cause receiver desensitization.

With adequate channel separation, the transmitter-receiver multicoupler configuration offers the advantages of maximum antenna consolidation and also provides sufficient filtering to eliminate major RFI problems such as intermodulation and desensitization.

If the frequency assignments for the Oakland area (ZOA) are reviewed, it is seen that the currently assigned frequencies are well separated in most cases.

Exhibit 6-7

MULTICOUPLER CONFIGURATION

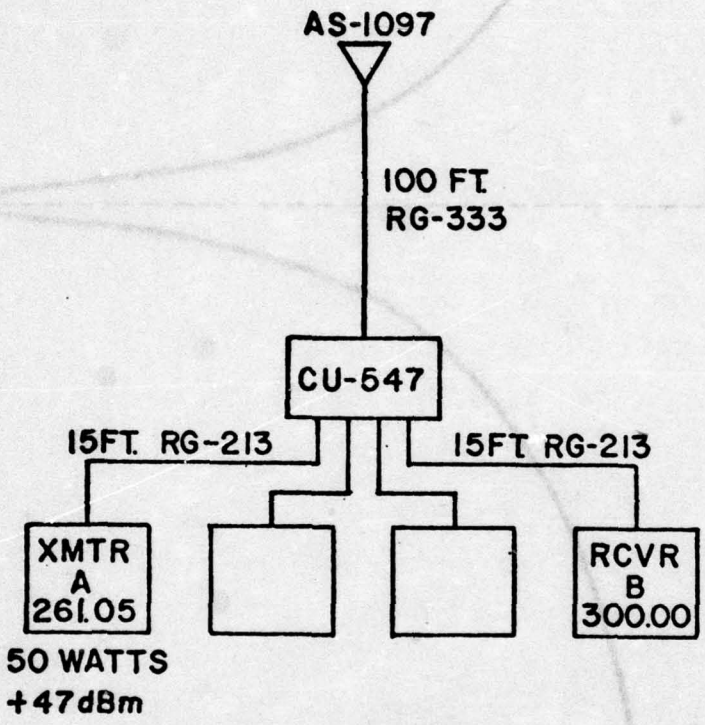
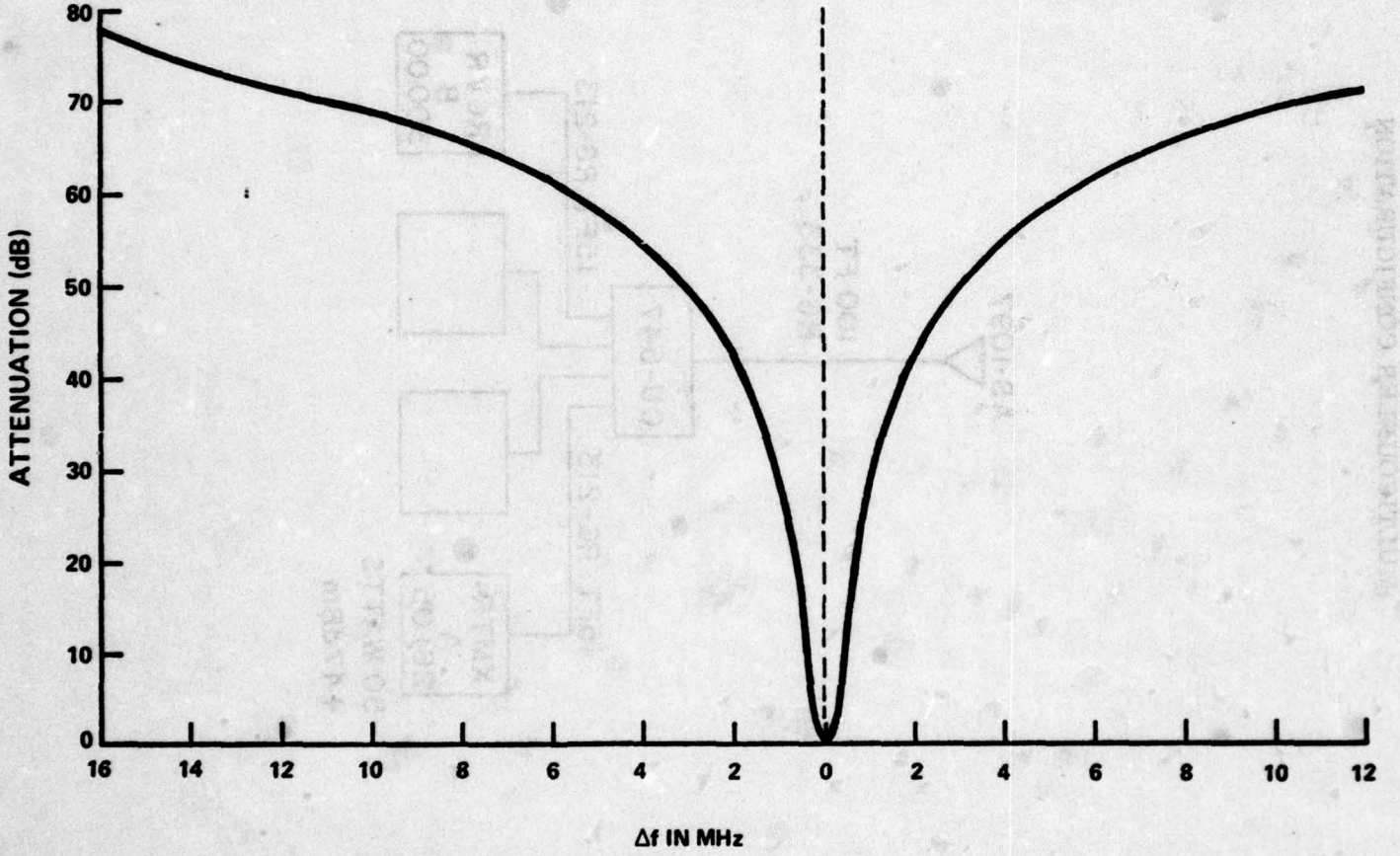


Exhibit 6-8

CU-547 ATTENUATION VS. FREQUENCY ± 12 MHz



Source: AFCS Technical Manual TO 312-10-17, October 1974.

Exhibit 6-9 shows the minimum frequency separation at the en route facilities.

At VHF, the separation ranges from 350 kHz to 5.65 MHz.

At UHF, the separation ranges from 3.1 MHz to 28.1 MHz.

Assignment of additional frequencies to radio facilities would tend to decrease the current separation.

6.3 SUMMARY

Exhibit 6-10 shows two alternative configurations that provide antenna consolidation through the use of multicoupler devices.

Exhibit 6-10A represents an arrangement similar to that of the Air Force and employs the coupler AN/Cu-xxx as specified (MME 75-149). Assuming the filters specified are realizable, the 50 db isolation between ports is adequate for RFI supression if the frequency separations are maintained at greater than 3 MHz for VHF and greater than 5 MHz for UHF. It was noted in the example of ZOA assignments that separations as low as 350 kHz occur. The minimum UHF separation of 3.1 MHz for ZOA is also less than that specified (5 MHz).

This does not eliminate the configuration from consideration, because, as Exhibit 6-9A shows, only one of four available towers is used. The use of two towers would allow a division of channels so that with two multicouplers, the smaller frequency separations would be feasible.

Exhibit 6-10B shows a configuration that employs a transmitter combiner for the multiple transmitters, and an active multicoupler for the multiple receivers. This arrangement is more suitable for handling the close separation of frequencies that are likely to occur in support of FAA operations.

Either of the above configurations is responsive to the objectives discussed in section 6.1.

The current physical plant and layout may be retained; and a significant expansion of channel capability is possible for colocation of air/ground radio functions, and

Exhibit 6-9

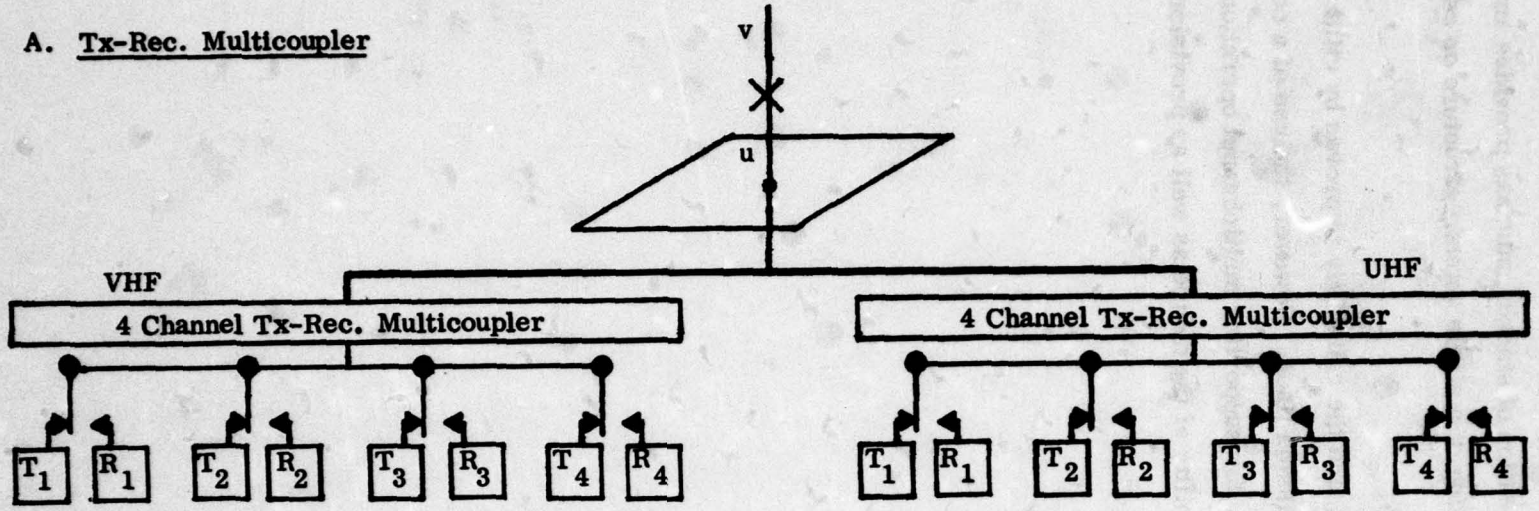
MINIMUM FREQUENCY SEPARATION (ZOA RCAGS)

SITE	ΔF	
	VHF (MHz)	UHF (MHz)
Angels Camp 1	0.35	29.5
Angels Camp 2	3.6	3.1
Fallon	2.4	6.2
Ferndale	0.60	6.2
Fresno 1	4.35	3.90
Fresno 2	1.65	13.8
Mina	5.0	20.5
Mountain View	1.55	8.0
Mt. Tamalpais	4.4	30.5
Priest	0.8	12.1
Red Bluff	0.75	8.9
Reno	5.65	16.2
Tonopah	4.75	28.1

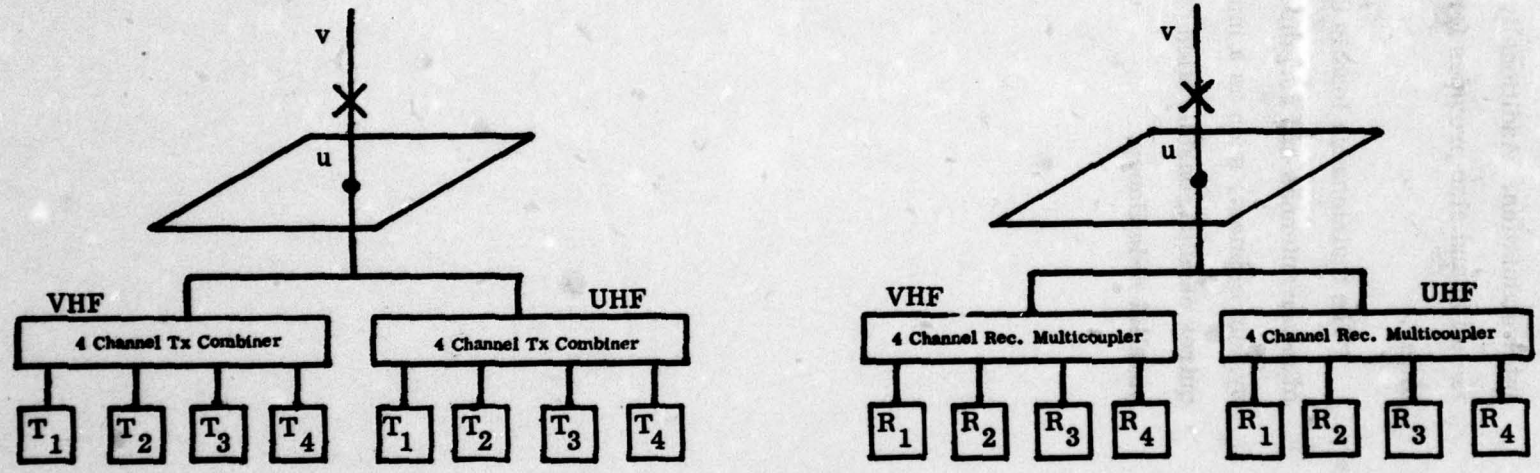
Exhibit 6-10

ALTERNATIVE MULTICOUPLER CONFIGURATIONS

A. Tx-Rec. Multicoupler



B. Tx Combiner-Rec. Multicoupler



backup channels for gap filling operations. The use of filters in the transmitter combiners also contributes to the minimization of RFI--particularly transmitter intermodulation. Additionally, the application of stacked antennas provides antenna isolation and also provides for the mounting of a single antenna structure on each tower.

The maintenance load is diminished, and the reliability improves by utilization of fewer antennas and associated transmission lines. However, the use of a common system element, such as a multicoupler, for supporting multichannel operations requires careful consideration of the reliability of the device as well as provisions for parallel redundancy.

7

EXPERIMENTAL EVALUATION

7.1 INTRODUCTION

As discussed in earlier sections of this report, the performance of an antenna system in an operational environment is the sum of a number of contributing factors. The objective of the experimental part of the program was to logically separate the various perturbation effects and to evaluate the contribution of each. Starting with the free space pattern of specified antennas, the experiments were planned: to isolate and identify distortions due to proximity of antennas to one another as well as to nearby tower structures and mounting hardware; to measure the various RFI phenomena such as desensitization and intermodulation; to perform a series of flight tests of several operational antenna configurations for a relative assessment. Since flight tests are time-consuming, and expensive, and usually measure cumulative performance, the approach was planned to perform a number of static tests that would investigate distortion parameters.

The most effective procedure for conducting such tests is based upon an iterative process that modifies succeding experiments as a result of data inputs describing the various parameters of interest. Because of unavoidable delays encountered in the procurement of test antennas, construction of the necessary antenna mounting hardware, delivery of solid state radio equipment, and scheduling problems common to experimental facilities (like NAFEC) with multiple test programs, the 12-month duration of this project did not allow sufficient time to complete the anticipated experimentation or to significantly modify test plans as a result of collected data. Succeeding test and evaluation programs concentrating on air/ground communications should encounter far fewer difficulties since the test facilities are now active with a sizeable complement of supporting equipment and instrumentation.

Within the bounds of the established schedule, experiments were conducted in the areas of: 1) free space antenna pattern measurement, 2) antenna pattern distortion, and 3) antenna system flight tests. As to these three areas, the free space pattern measurements (scheduled as the initial series of tests) were sufficiently time consuming that the schedule for the remaining experimentation was compressed. The RFI tests were aborted due to late delivery of the solid state radios necessary for the test program.

The horizontal pattern distortion measurements that were performed are discussed in section 4.1. The distortion of antenna patterns in the horizontal plane of a vertical dipole represent a complex process with no satisfactory theoretical treatment available. By carrying out a significant sample of tests over a wide variety of proximity conditions, a fuller investigation of the phenomena involved was anticipated. The sample of data collected is limited and should be examined from that point of view.

The flight test experimentation was limited to a total of six flights. The maximum mix of antennas and relative operational configurations were employed within the available schedule. However, all desirable combinations were not tested and no provision for reruns was possible.

The above factors are noted to stress the fact that the results of the experimental evaluation must be categorized as indicative rather than conclusive. The sample size of the data is insufficient to fully explain and quantify the performance measurements.

The following sections describe the experimental evaluation of individual antennas and antenna systems in an operational environment.

7.2 ANTENNA TEST PROGRAM

The antenna test program was carried out as a joint undertaking in response to the requirements of this project and to a related requirement expressed by AAF-440. The NAFEC facility, through the use of its antenna test range (see Exhibit 5-15), performed a series of experiments on single antennas for the purpose of measuring the VSWR, the gain, and the horizontal and vertical free space patterns.

The purpose of the experimentation was to investigate the performance of a cross-section of available antennas, as well as those in the current FAA inventory, to explore the potential for improved application in the field.

This study looked at antenna systems for en route facilities that involve the use of multiple antennas in a low margin signal environment. Therefore, a major interest in the experimentation with antennas focused on methods to increase antenna to antenna isolation and to compare signal margin through antenna gain.

A survey of available antenna technology was conducted, and, on that basis, a number of representative antennas were processed for evaluation. A listing of antennas tested appears in Exhibit 7-1. It can be seen that the group of antennas includes types from the current FAA inventory as well as various available products from industry.

The types tested fall into several generic classes:

(1) simple vertical dipoles,

(2) stacked dipole antennas,

(3) complex (collinear array) omnigain antennas,

(4) directional gain antennas, and

(5) narrow-band antennas.

It became evident during the investigation that several bounds exist to limit the performance of antennas:

(1) Physical Size. Stacking antennas within a single radome at VHF is limited because of length and weight considerations. It appeared that two antennas (e.g., a VHF-UHF or UHF-VHF combination) comprises a reasonable configuration. These antennas are usually single dipole gain configurations for each element since phasing elements to obtain omnidirectional gain will extend the length.

(2) Omnidirectional Gain. Complex antennas derived from phased collinear arrays are limited in gain by the number of dipoles placed in line. The voltage gain increases as $\sqrt{n}$, where n is the number of dipoles. This

Exhibit 7-1

LIST OF TESTED ANTENNAS

	TYPE	FREQ
KRECO SC-155BN	Stacked Coax	127 MHz
KRECO VB-155BN	Directional	127 MHz
KRECO CP-156A	Dipole	122 MHz
KRECO CO-156A	Dipole	122 MHz
TACO D-2216A	Dipole	VHF
TACO D-2212	Muldipol	(V-V)*
TACO D-2260	Muldipol	(V-V-V)
TACO D-2217	Dipole	UHF
TACO Y-102B-130	Yagi	VHF
TACO YS-102B-130	Stacked	VHF
FA-5668	Discone	UHF
FA-7957A	Dipole	VHF
FA-9430	Swastika	VHF
TACO Y41-129	Screen Yagi	127 MHz
TACO D-2216B	Dipole	118-123 MHz
TACO D-2216C	Dipole	123-129 MHz
TACO D-2216D	Dipole	132-136 MHz
TACO D-2261A	2 Bay Gain	118-136 MHz
TACO D-2262	2 Bay Gain	225-400 MHz
TACO D-2218	Muldipol	(V-U-V)
TACO D-2118	Muldipol	(U-V-U)
TACO D-2213	Muldipol	(V-U)
Phelps Dodge Low	Gain Coax	118-123 MHz
Phelps Dodge Mid	Gain Coax	123-129 MHz
Phelps Dodge High	Gain Coax	132-136 MHz
DB Products DB-224	Folded Dipole	118-136 MHz
DB Products DB-230	Directional	127 MHz
DB Products DB-286	2 Bay Directional	127 MHz
Antenna Products OPV-22	Gain	UHF
Collins 437B7	Gain	UHF
Scientific Atlanta 15-115	Std Gain	VHF
Scientific Atlanta 100-174	Log Periodic	VHF
AT-197	Discone	UHF
CA-1594	Coax Dipole	118-123 MHz
FA-5248	Coax Dipole	116-144 MHz
FA-5675	Swastika	116-144 MHz
Radionics	Dipole	VHF
Radionics	Dipole	UHF

*V-VHF
U-UHF

maximum assumes a vertical separation between antennas of approximately .5 λ which is not normally employed. Thus a two dipole array will provide approximately 3 db gain over a single dipole. Since the radiated power is constant, the gain is derived by pattern modification which extends the signal level in the major lobe at the expense of 90-degree coverage (overhead).

(3) Directional Antennas. Directional antennas are available with nominal values of 10 to 15 db gain. However, their use limits the application of antenna combining methods such as multicouplers. Since multicoupler employment offers a number of advantages for responding to requirements for a multichannel facility, it appears that the use of directional antennas should be limited to special problem areas.

(4) Narrow Band Antennas. Narrow-band omnidirectional antennas are simpler in construction than wide-band antennas and offer an advantage in gain and isolation over wide-band antennas. However, their use with multicouplers is restricted to a corresponding narrow band of frequencies. Additionally, their use in previous periods by FAA resulted in inventory and logistical problems by adding appreciably to the required stock of different antennas.

Each antenna was checked for VSWR, gain, and horizontal and vertical patterns. The measurements were taken for low, mid, and high band frequencies. The measurements followed the various manufacturer's specifications in almost all cases. A number of the antennas tested were sensitive to the type of mounting hardware employed and suffered distortion when mounted on metallic pipes as normally used in the field.

A complete set of measured characteristics for all the antennas listed in Exhibit 7-1 can be found in a NAFEC publication (publication information currently unavailable).

7.3 EXPERIMENTAL FLIGHT TESTS

The experimental flight tests were planned to assess antenna system performance in an operational environment. The collection and evaluation of data about the static tests of specific antennas (singly and in multiple configurations) was to provide inputs describing the various distortions to be expected. This approach proved successful to the extent that the schedule allowed. The use of center mounted (center of tower platform) single antennas utilizing nonmetallic mounts resulted in the measurement of regular patterns in the horizontal plane without any evidence of severe distortion.

The experiments conducted evaluated the use of single and multiple antennas mounted in various configurations. Variations in antenna height effects were assesed. Both stacked and omnidirectional gain antennas at VHF and UHF were tested. First order measurements were conducted to evaluate the perturbations introduced by the aircraft antenna as a function of altitude.

Note that the objective in the measurement of antenna system performance was to obtain a relative evaluation of generic types of antennas (i.e., dipole, stacked, collinear, and narrow band) including those in the current FAA inventory. When a specific manufacturer's antenna is used, it is considered a representative element of those available and not an endorsement.

It was evident that some of the data collected would develop interest in further experimentation. This, in fact, occurred, and recommendations for follow-on work are presented in Chapter 9.

7.4 EXPERIMENTAL SETUP

The measurement setup used for the experimental flight test consisted of the major elements shown in Exhibit 7-2. This system consisted of a ground station where a receiving system was located, an antenna system, an aircraft transmitting system, and, although not depicted explicitly, the propagation path.

7.4.1 Receiving System

A block diagram of the receiving system is shown in Exhibit 7-3. This setup was located in building 176 (a typical RCAG type building) at NAFEC.

Exhibit 7-2

BLOCK DIAGRAM OF FLIGHT TEST SCHEME

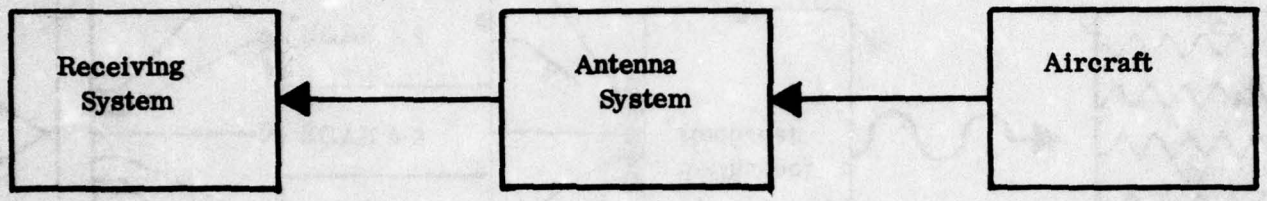
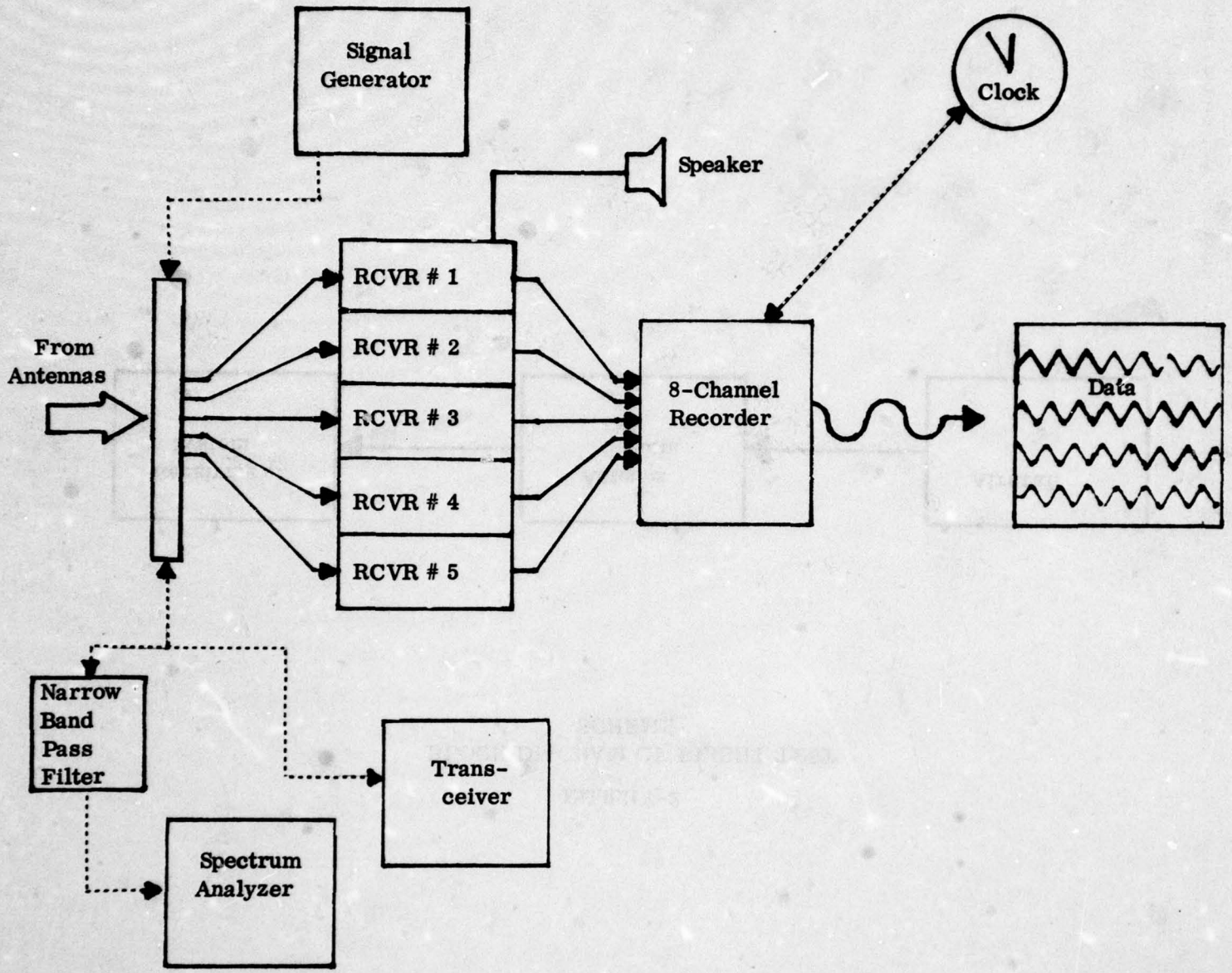


Exhibit 7-3

GROUND TEST EQUIPMENT SETUP



Signals coming from the antenna system were routed via a cable bus to the building. These cables, in turn, were connected to a bank of FAA radio receivers. The radio receivers used were older tube types (e.g., RV-2 and RV-8) now being phased out from FAA use. These receivers were used because of the wider linear, nonsaturated AGC dynamic range in contrast to the newer solid state receivers whose AGC saturates at lower values of input signal (i.e., more nonlinear). A speaker was connected to the phone jack of one of the receivers to monitor appropriate mission milestones relayed by the flight test team member aboard the aircraft.

The bank of receivers was then connected to an eight-channel pen recorder that plotted the received AGC versus time. Only five of the eight recording channels were used at any time. The remaining three were used to jot down miscellaneous comments such as time information, position information, and aircraft system VSWR.

Peripheral to the direct recording system described above were other instruments used to aid in the data collection.

At the antenna/receiver interface, several items were used:

(1) A RF spectrum analyzer connected through a narrowband filter tuned to the experimental frequency of the day. This analyzer was used to monitor the experimental signal and to serve as a backup if one of the recorder channels failed (it was once used as a backup).

(2) A radio transceiver used to monitor the ATC interchange between the aircraft pilot and the NAFEC control tower. It was occasionally used to communicate instructions (e.g., premature mission abort) to the aircraft pilot from building 176.

(3) A RF signal generator used to calibrate the recorder, based on the AGC behavior of each receiver and the signal input of the generator, so that the recording could be directly interpreted as signal power levels.

(4) A wall clock used to monitor time. A time mark was placed on the data record at five-minute intervals.

In addition to these elements located at Building 176, a tracking radar was used to plot a time versus azimuthal position graph for the aircraft. This radar track was subsequently used to reduce the signal level versus time record to a signal level versus position plot.

7.4.2 Aircraft System

The aircraft system basically consisted of a transmitter at 10 watts output power, some means for measuring VSWR at the transmitter output, and an antenna on the aircraft fuselage. Exhibit 5-43 shows the location of the aircraft antenna on the fuselage and some characteristics of the aircraft used.

7.4.3 Antenna System

The antenna system was the variable element of the experiments. It consisted primarily of four antenna towers spaced 80 feet apart in a standard RCAG configuration about the building. The antennas under test were mounted in various ways (as needed by a particular flight test) on the platform of the antenna towers. Exhibit 7-4 shows the site configuration (top view) with the antenna tower placement. In addition to the fixed towers (which are approximately 55 feet in height), a portable crank-up tower was also used during the experiment. The portable tower (which accommodates one antenna) was used at heights of 35, 45, and 48 feet. The full potential of the portable tower was not always available (maximum height 55 feet) since the tower cranking mechanism malfunctioned on several flight tests. The portable tower was located as shown in Exhibit 7-4, about 40 feet from the closest neighboring tower.

7.4.4 Propagation Environment Considerations

One of the significant factors influencing the propagation environment at the NAFEC site was the small forested area close by. The trees in this forest affected the propagation somewhat as will be seen below. The antennas placed on the portable tower had the greatest degradation due to the trees. The trees were about 25 to 35 feet tall. The approximate distances of the tree line around the site are shown in Exhibit 7-5.

Exhibit 7-4

TOP VIEW OF SITE CONFIGURATION

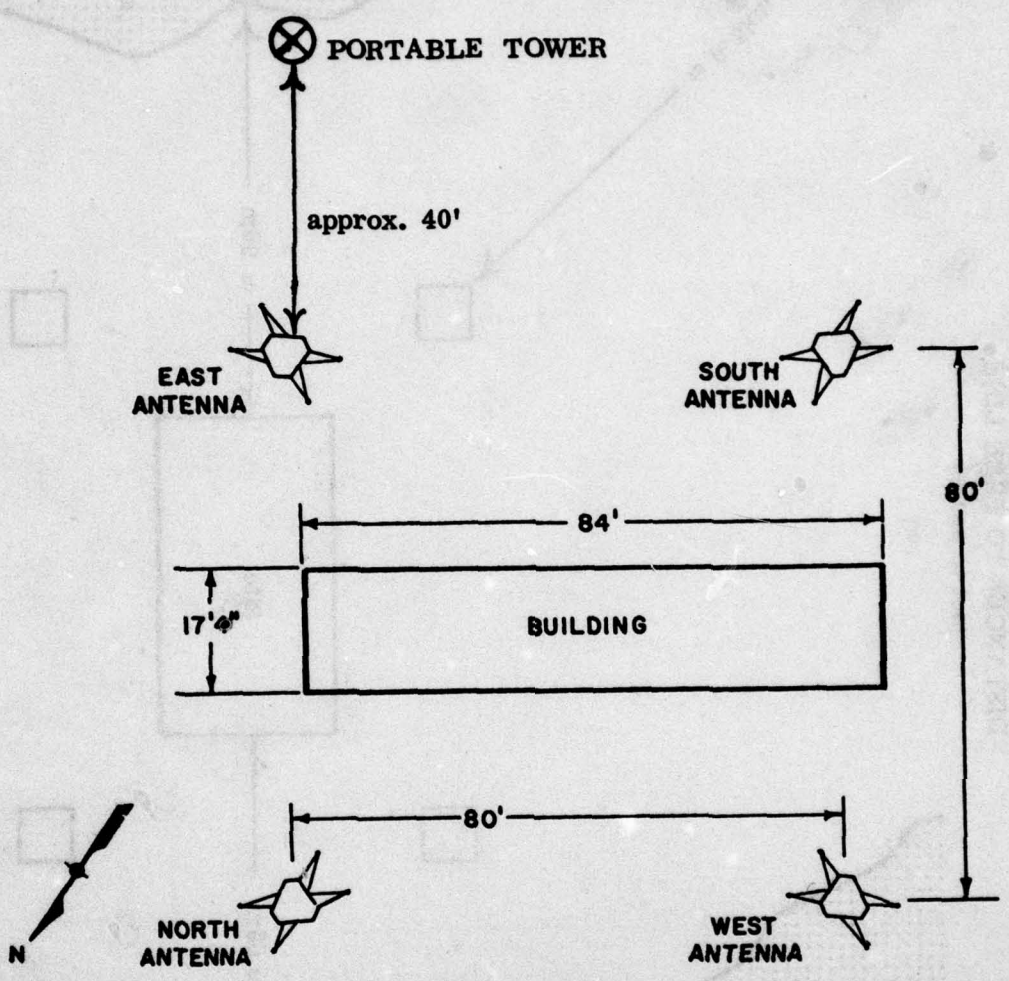
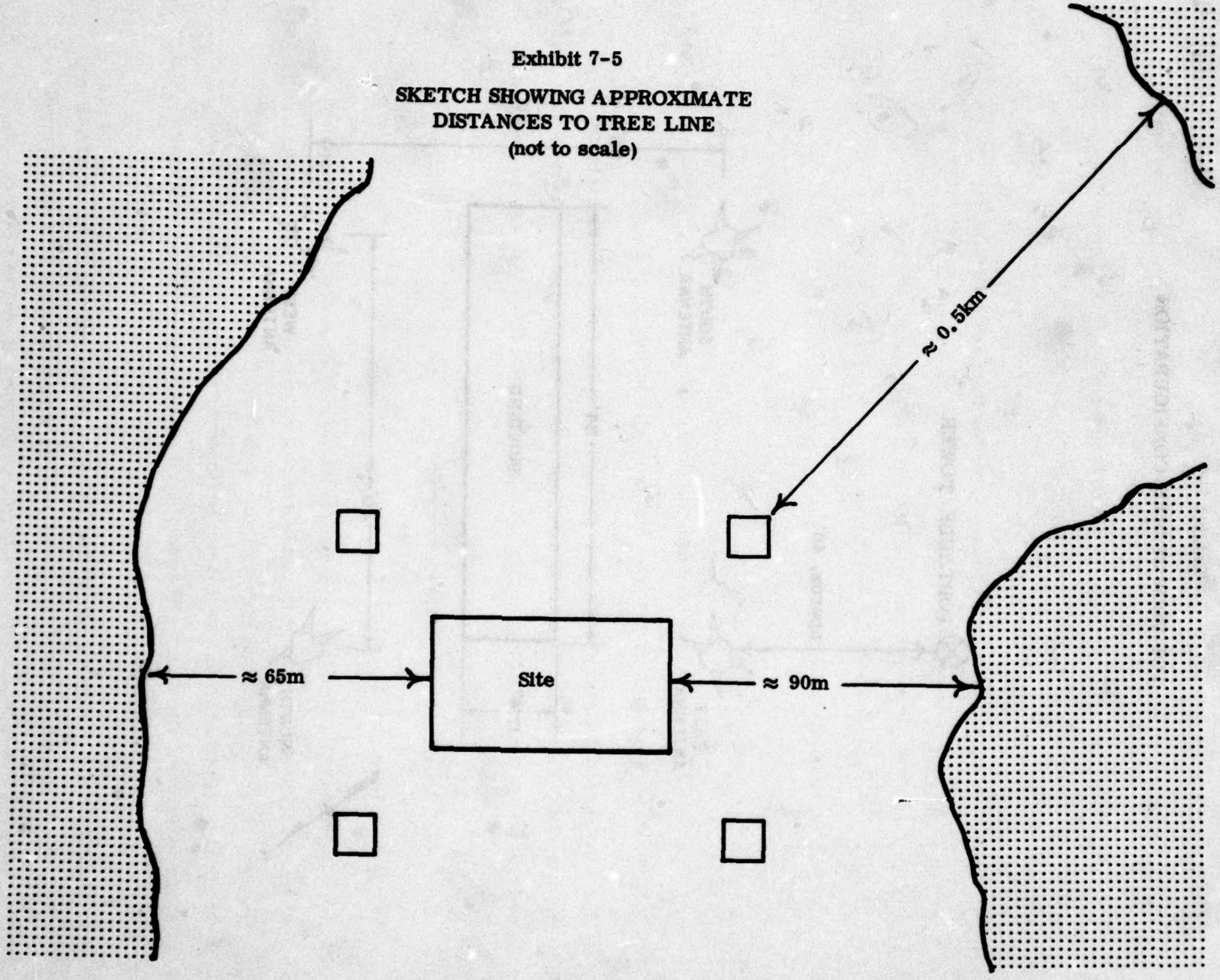


Exhibit 7-5

SKETCH SHOWING APPROXIMATE DISTANCES TO TREE LINE
(not to scale)



The trees affected propagation in several ways:

(1) At long ranges (e.g., 20 to 25 nm) and low altitudes (e.g., 3,500 to 4,000 feet), there is a complete loss of direct line of sight (LOS) to the aircraft by the portable tower at certain orbital quadrants.

(2) At closer ranges, and at long ranges for the fixed towers, there is some signal attenuation even with LOS available, because, in most cases, there is not complete first Fresnel zone clearance of the direct wave.

(3) The absorbtion effect of the trees severely attenuates the reflected rays. This, however, helps alleviate possible multipath effects.

Another factor which may have affected the results is the fact that there were portions of the flights both over water and over land during tests.

Finally, although the results show certain anomalies that could be explained by the presence of obstacles (such as the antenna towers or other antennas), these degradation factors were not pursued in these experiments; thus, they are not addressed here.

7.5 TEST AND ANALYSIS PROCEDURES

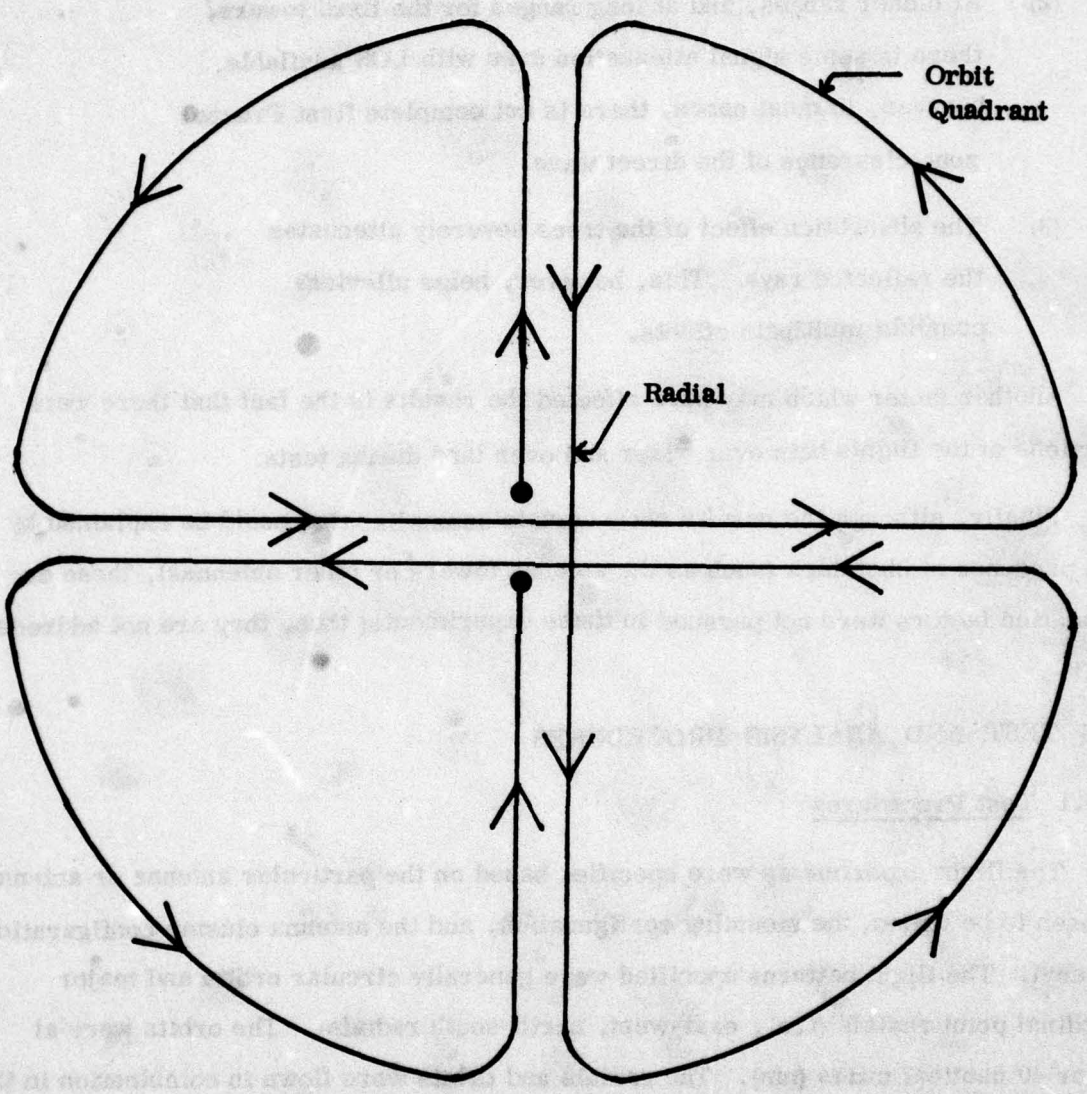
7.5.1 Test Procedures

The flight experiments were specified based on the particular antenna or antennas chosen to be tested, the mounting configuration, and the antenna cluster configuration (if any). The flight patterns specified were generally circular orbits and major cardinal point radials (i.e., east-west, north-south radials). The orbits were at 25 or 40 nautical miles (nm). The radials and orbits were flown in combination in the pattern shown in Exhibit 7-6.

Additionally, one other type of test was performed involving a cloverleaf pattern. This flight helped determine the performance of the antennas for different aircraft altitudes and was an attempt to get a handle on the aircraft antenna pattern.

Exhibit 7-6

TEST FLIGHT PATTERN



Other housekeeping items such as systems calibration and test schedule were also specified for each flight test. An example of a flight test specification is shown in Exhibit 7-7.

7.5.2 Data Analysis Procedures

A segment of the raw test data is shown in Exhibit 7-8. This data, which is time marked and for which there is a signal level calibration before and after the test, was reduced based on the tracking radar plot (Exhibit 7-9) to radial (Exhibit 7-11) or polar plots (Exhibit 7-11) or both. The plots and the actual data track were used for a comparative analysis of the different antenna patterns in a given test.

The major quantitative comparative criteria used to compare the antenna patterns were:

(1) the mean signal level of an antenna pattern over a 360-degree orbit.

(2) the average absolute deviation (in percentage) of the data points (which were signal levels at 10-degree intervals) from the mean, where this average deviation is defined as

$$\overline{\%d} = \frac{\sum_{i=1}^{n} \%d_i}{n}$$

where

$$\%d_i = \frac{S_i - \bar{S}_i}{S_i} \times 100$$

and

S_i = signal data point

$\bar{S}_i$ = mean signal level

The latter indicator gives a measure of how close an antenna performance is to omnidirectionality at a signal level equal to the mean value. Also included for a relative comparison is the deviation of the mean value of the signal from the free space value of the signal at 25 or 40 nautical miles with +40 dbm transmitted power and isotropic antennas (0 dBi). The signal level due to free space loss only, at a frequency of 126.25 MHz, for a +40 dbm signal is:

(1) -65.36 dbm at 25 nmi

(2) -69.45 dbm at 40 nmi

Exhibit 7-7

SAMPLE FLIGHT TEST SPECIFICATION

TEST PLAN - PART I **1Aug. 1977**

ANTENNA SYSTEMS ANALYSIS, TEST, AND EVALUATION

TEST OBJECTIVE

This test is one of a series to collect radio signal data to be employed for the analysis and evaluation of antenna system operation in support of air/ground communications.

PURPOSE

TEST PLAN - PART I is designed to accomplish the following:

(1) Identify the general propagation characteristics relative to the NAFEC Radio Site Facility.

(2) Identify areas of stable signal conditions for subsequent tests.

(3) Isolate and characterize several antenna/tower configurations

(4) Initiate the determination of aircraft antenna radiation characteristics.

GROUND CONFIGURATION - NAFEC RADIO FACILITY

1. Four antenna configurations are to be evaluated as a function of the following positions.

(a) PORTABLE TOWER - Height 35 feet. Antenna - TACO D-2216 A Mounted on 4 ft length of non-metallic tubing.

(b) FIXED TOWER #1 - Antenna - TACO D-2216 A. Mounted in geometrical center of tower on 4 ft. length of non-metallic tubing. Base of mount co-planar with tower railing.

(c) FIXED TOWER #2 - Antenna TACO D-2216 A. Mounted on end of outrigger on 4 ft. length of non-metallic tubing.

(d) FIXED TOWER #3 - Antenna FA-5675(Swastika) . Mounted in geometrical center of tower on 4 ft. length of non-metallic tubing. Base of mount co-planar with tower railing.

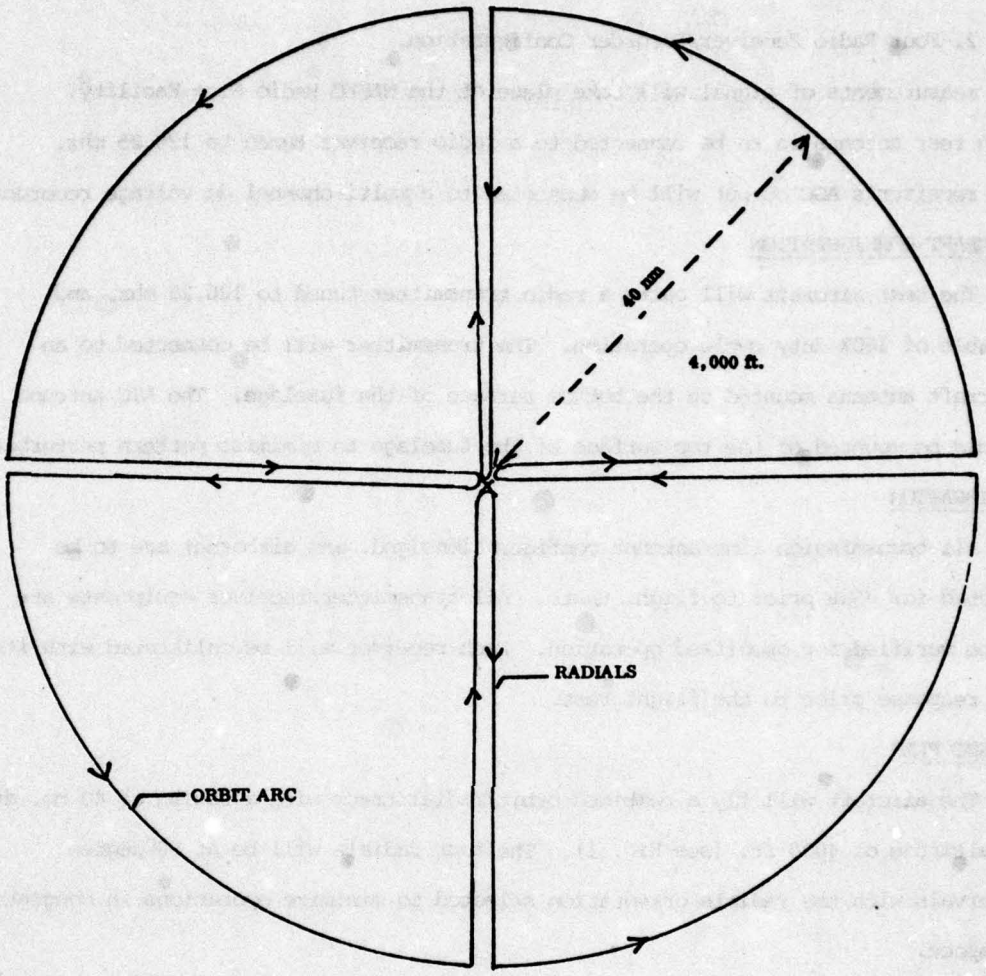


FIGURE 1 FLIGHT TRACK

PROCEDURE

Recording of data will begin with aircraft entry into flight pattern. The aircraft transmitter will be keyed continuously during the test flight. For each segment of flight entered(arc or radial) the steady state condition of flight will be annotated on the AGC recording. Flight operations are to be maintained level at 4000 ft. consistent with flight conditions and safety.

TEST SCHEDULE AND DURATION

Test is scheduled to take place on 16 August 1977 and is estimated to consume 3 hours of flight time. *

* Note - If 3 hours is considered excessive then orbit and radials can be exercised in sequence with two flights. (Data will lose some validity)

2. Four Radio Receiver/Recorder Configuration.

The measurements of signal will take place at the NAFEC Radio Site Facility. Each test antenna is to be connected to a radio receiver tuned to 126.25 mhz. The receiver's AGC output will be connected to a multi-channel dc voltage recorder.

AIRCRAFT CONFIGURATION

The test aircraft will carry a radio transmitter tuned to 126.25 mhz. and capable of 100% duty cycle operation. The transmitter will be connected to an aircraft antenna mounted on the bottom surface of the fuselage. The ATC antenna should be mounted on the top surface of the fuselage to minimize pattern perturbation.

CALIBRATION

All transmission line/antenna configurations(gnd. and airborne) are to be checked for VSWR prior to flight tests. All transmitter/receiver equipments are to be verified for specified operation. Each receiver will be calibrated with its AGC response prior to the flight test.

FLIGHT PLAN

The aircraft will fly a combined orbit/radial track with a radius of 40 nm. at an altitude of 4000 ft. (see Fig. 1). The four radials will be at 90 degree intervals with the radials orientation selected to minimize operations in congested airspace.

FLIGHT TRACKING AND DATA CORRELATION

x,y position of the aircraft will be recorded by the NAFEC Facility employing one or a combination of available techniques. ie. radar, VOR/DME, TACAN. The flight track and the AGC data will be time annotated to allow correlation.

ORDER WIRE

A communication channel between the aircraft and the NAFEC Radio Site Facility will be established as an order wire to enable correlation of collected data with aircraft positional information.

Exhibit 7-8

SEGMENT OF RAW TEST DATA

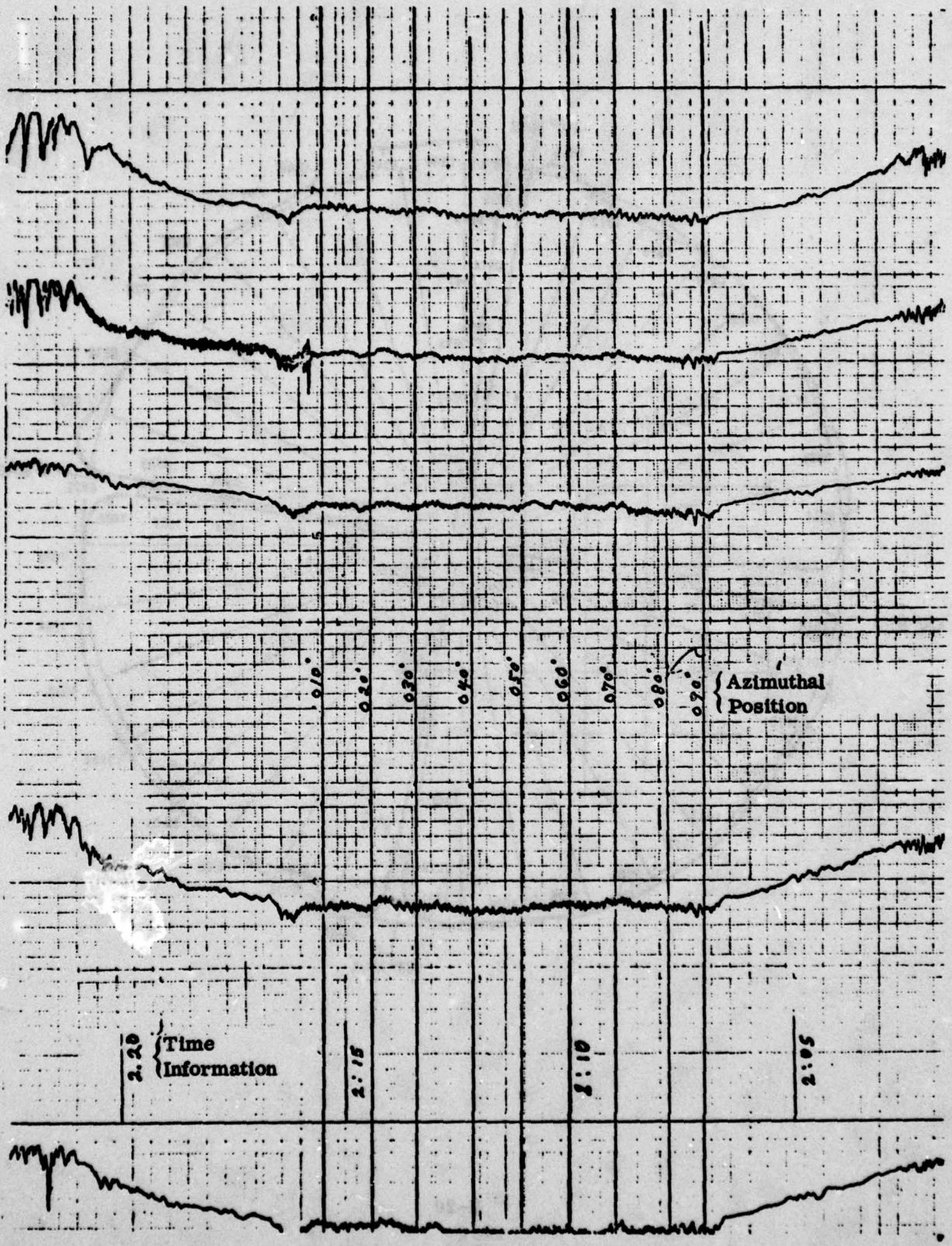


Exhibit 7-9

RADAR TRACK WITH ANGULAR MARKINGS

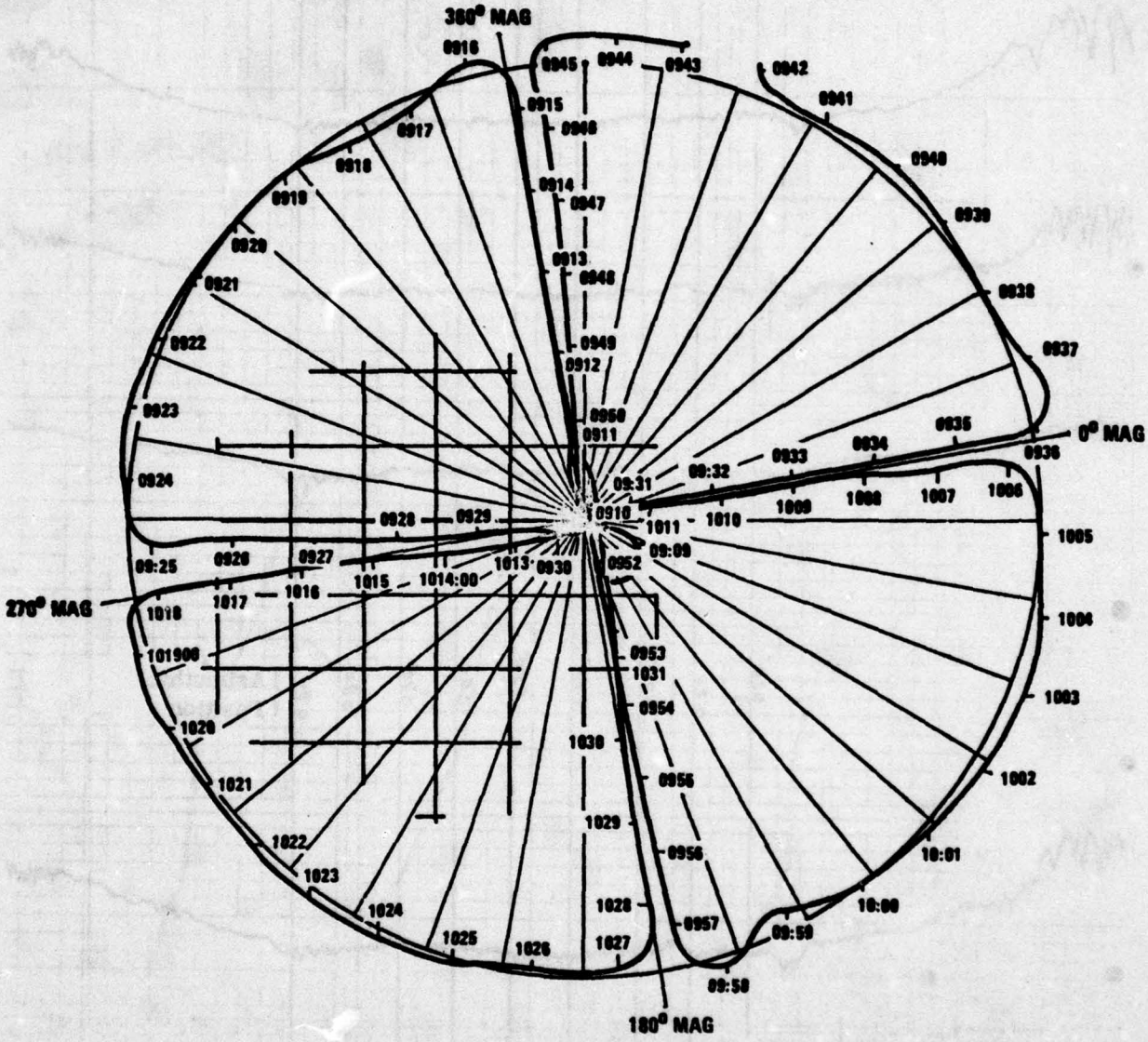
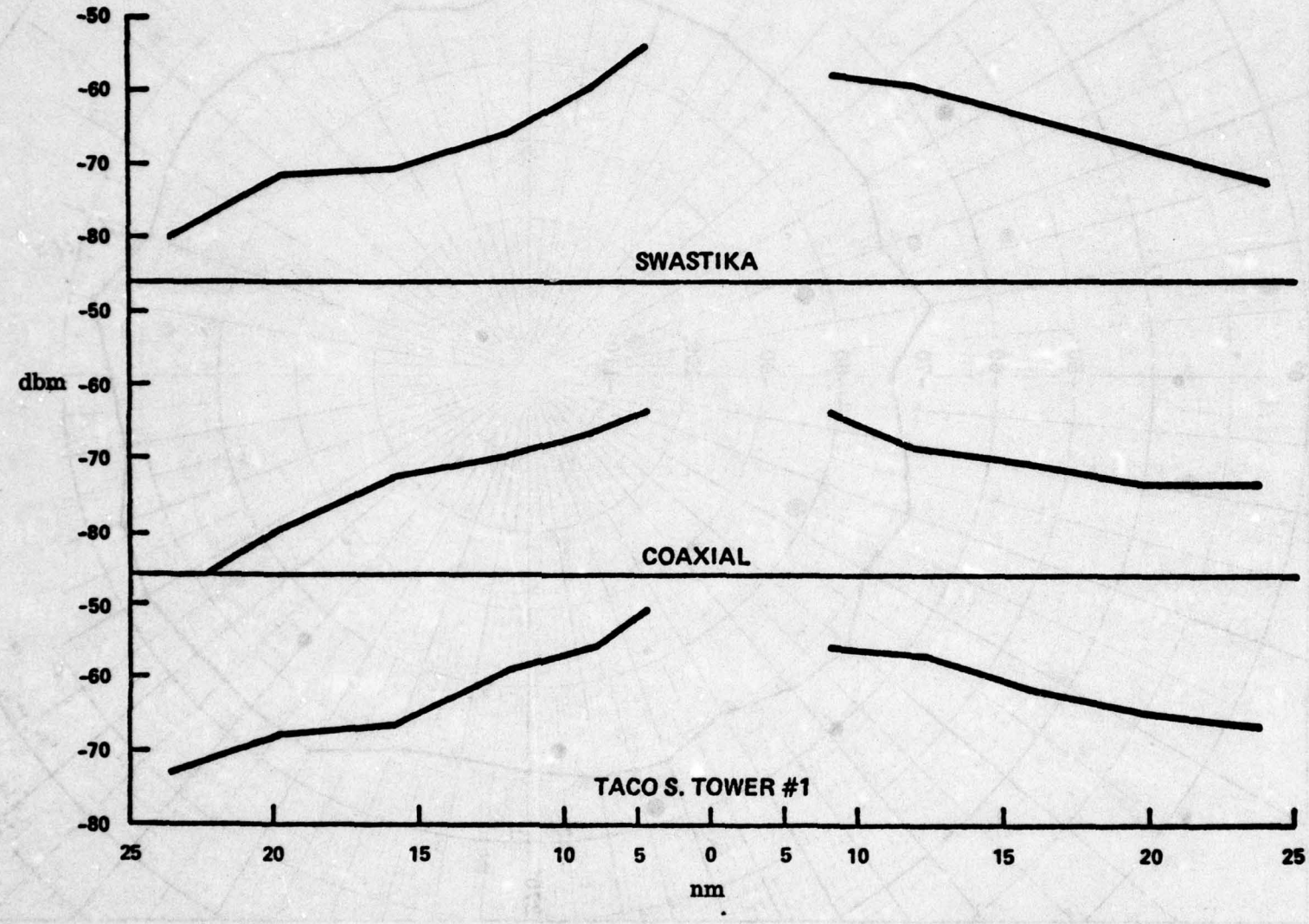


Exhibit 7-10

EXAMPLE OF RADIAL PLOT



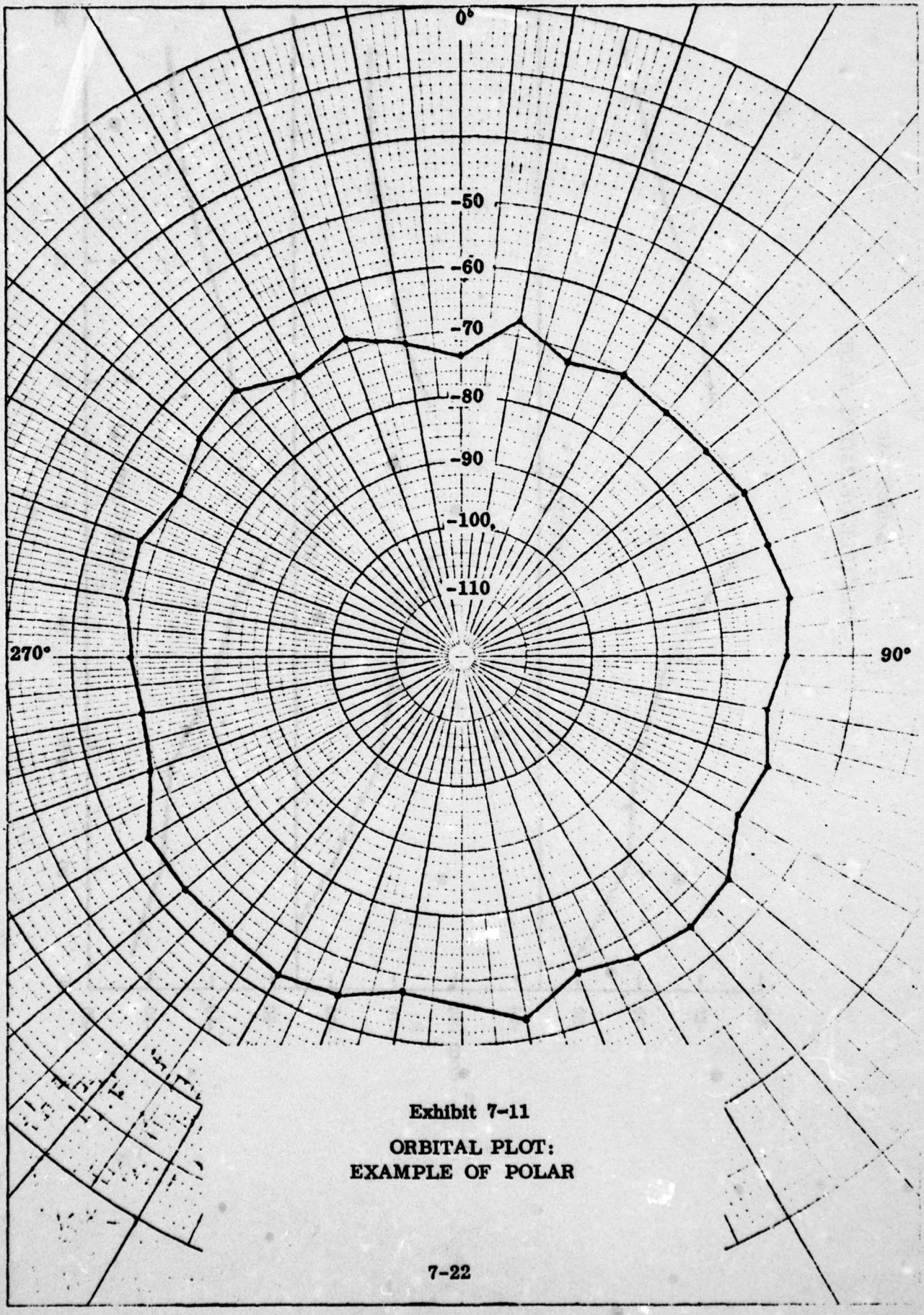


Exhibit 7-11

ORBITAL PLOT:
EXAMPLE OF POLAR

The difference measure is then defined as:

$$\Delta_{fs} = S_{fs} - \bar{S} \text{ db}$$

where

S_{fs} = free space signal as defined above

$\bar{S}$ = actual mean signal level in dBm

Different criteria were used in the comparison among antennas for the cloverleaf flight pattern test. These will be examined below in the section documenting the results of this test.

7.6 FLIGHT TEST RESULTS

The flight tests for purposes of this report are grouped into five experiments. Some of the experiments had flight tests performed on different days and, in some cases, with minor ground or airborne equipment configuration changes. However, these changes affected the results minimally.

The five experiments were:

(1) A 270° orbit flown at 40 nautical miles (nm) which examined the performance of several single VHF antenna configurations.

(2) A cloverleaf pattern flown with the same configurations as in (1).

(3) Several VHF antennas tested in multiple antenna configurations with a 25 nautical mile orbit. This test included several gain and stacked antennas.

(4) This experiment examined single antenna configurations of UHF antennas. A 25 nm orbit was flown.

(5) This experiment examined the effect of different vertical extension mounts on antenna performance. The TACO single VHF dipole was used and a 25 nm orbit flown.

7.6.1 Experiment No. 1

The purpose of this experiment was to examine the differences in performance that occur when mounting a VHF dipole (vertically polarized) in the center of the antenna tower as compared to mounting a 4-foot swing-arm extending away from tower railing (called outrigger in the text). A circularly polarized swastika was also compared in these two modes at the same time so that comparisons could further be made between the swastika and the dipole. The dipole used was the TACO single VHF antenna. Two standard FAA swastikas (FA 5675 and FA 9430) were used.

The antenna configuration is shown in Exhibit 7-12 where the various circular symbols indicate the positions of the mounted antennas. The experiment was performed on two separate days. On the first day, one quarter orbit at 40 nm at 4500 feet was flown and on the second day one-half orbit was flown for a total of three-quarters of a full orbit. The last orbit quadrant was omitted because at this range the flight would have entered the Philadelphia TCA. The frequency of operation was 126.25 MHz. The resultant orbital plots for the data from this experiment are shown in Exhibits B-1 through B-5 in appendix B.

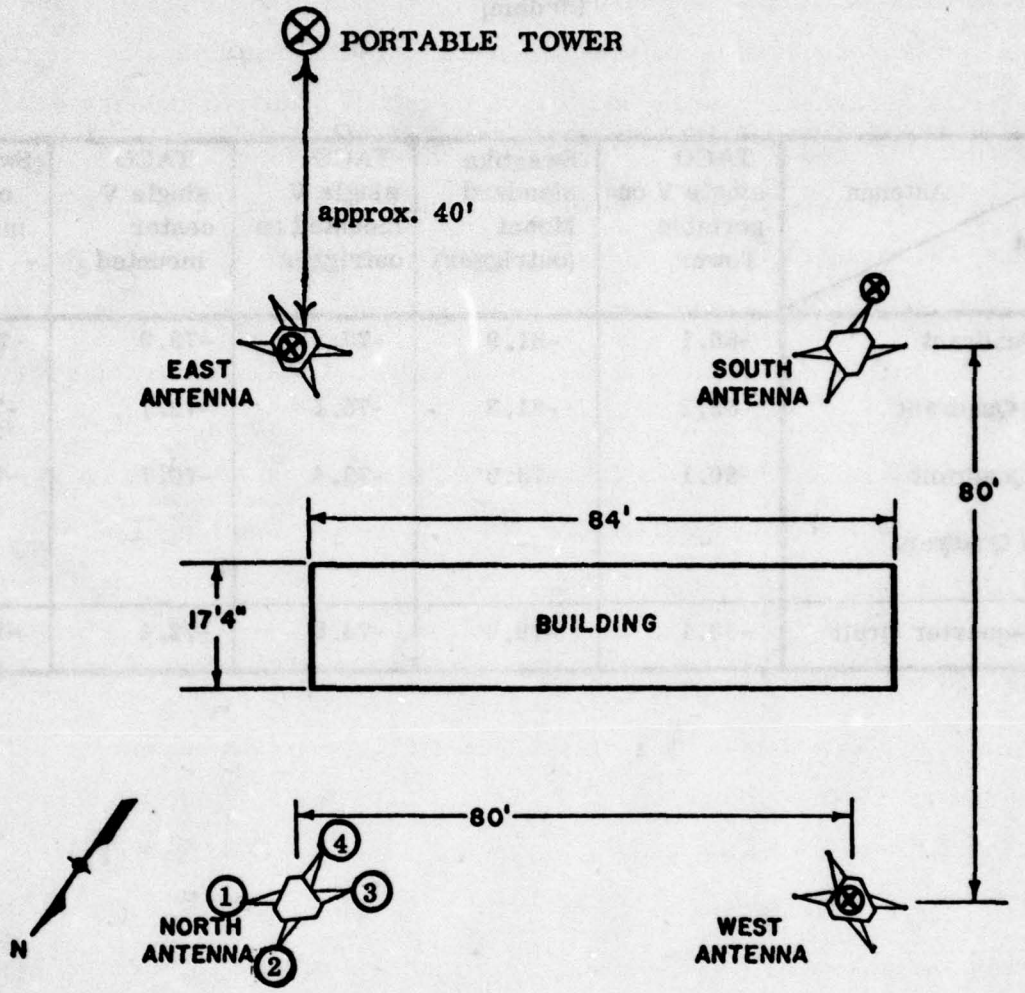
Exhibit 7-13 is a table of the average signal level due to each antenna by orbital quadrant. The purpose for using a quadrant average is to allow a more detailed comparison between antennas. Exhibit 7-14 shows the table of the results based on the analysis procedure outlined above.

From these results, it is clear that overall the best performing antenna is the center-mounted TACO single VHF dipole. It performs about 2.5 db better than the TACO single VHF mounted on the outrigger and about 5 db better than the center mounted swastika.

The swastika mounted on the outrigger performed the worst of the group of tested antennas on fixed towers. This performance may have been due to the fact that it was in a standard configuration (i.e., several other FAA antennas were in close proximity). The portable tower antenna, TACO single VHF, performed as expected because with a 35 feet tower height and at 40 nm, there is no LOS with the aircraft, and propagation is primarily by diffraction. The antenna performed

Exhibit 7-12

EXPERIMENT NO. 1 CONFIGURATION



ANTENNA CONFIGURATION BUILDING-176

North Tower (Standard RCAG Tower)

(1) FA-9430	(2) FA-7957	(3) AT-197	(4) AT-197
(used in test)	(unused)	(unused)	(unused)

East Tower TACO D-2216 Antenna center of tower on nonmetallic pipe 4' above tower rail

South Tower TACO D-2216 Antenna on nonmetallic pipe 4' above swing-arm mounting bracket

West Tower FA-5675 (Swastika) center of tower on nonmetallic pipe 4' above tower rail

Portable Tower TACO D-2216 on 4' length of nonmetallic pipe 35' above ground

Exhibit 7-13

MEAN SIGNAL LEVEL BY AZIMUTHAL QUADRANT
FOR EXPERIMENT No. 1
(in dbm)

Quadrant \ Antenna	TACO single V on portable Tower	Swastika Standard Mount (outrigger)	TACO single V mounted on outrigger	TACO single V center mounted	Swastika center mounted
First Quadrant	-86.1	-81.9	-75.8	-73.9	-77.4
Second Quadrant	-83.2	-81.3	-75.1	-72.7	-78.1
Third Quadrant	-80.1	-73.9	-73.4	-70.7	-75.7
Fourth Quadrant	-	-	-	-	-
Three-quarter Orbit	-83.1	-79.0	-74.8	-72.4	-77.1

Exhibit 7-14

RESULTS OF EXPERIMENT NO. 1

Antenna	Mean Signal Level (dBm)	% d	ΔFS (dB)
TACO single V mounted on portable tower @ 35'	-83.1	4.13	-13.65
Swastika standard mount (outrigger)	-79.0	4.77	-9.55
TACO single V mounted on outrigger	-74.8	2.71	-5.35
TACO single V center mounted	-72.4	3.24	-2.95
Swastika center mounted	-77.1	3.16	-7.65

at about 10 db below the level (-72.1 dbm) that would have been expected if the tower had been 55 feet tall. This is in close agreement with theoretical results on radiating through foliage.*

The percentage deviation for all the patterns shows that the patterns were relatively smooth. Including the effects of the deviation, the signal levels spanned a range of 16.5 db (i.e., the difference between the antenna with the highest average signal and the antenna with the lowest average signal including deviations).

7.6.2 Experiment No. 2

This experiment used the same configuration as the previous one (see Exhibit 7-12). The objective of this experiment was to examine the effect on signal levels due to changing aircraft attitude. The flight pattern performed by the aircraft is shown in Exhibit 7-15. It is a cloverleaf pattern. Again, the operating frequency was 126.25 MHz.

The results of this experiment are summarized in the tables shown in Exhibits 7-16 and 7-17. The entries in Exhibit 7-16 show the average level of the signal in straight runs (column 1), the average signal level in turns (column 2), the average maximum signal in the turns (column 3), and the average minimum signal in the turns for each antenna. The straight run and the turn are defined on the data record as shown in Exhibit 7-18. The average signal in the turn was computed omitting the data points about signal null in the turn, because of the very short interval (Exhibit 7-19) over which this null region occurs. The signal levels for most of the antennas exhibited a signal enhancement over the average signal level in a straight run toward the end of some turns (Exhibit 7-20). All of the turns were left turns. This signal enhancement is recorded as the maximum signal in the turn interval.

Exhibit 7-17 shows the changes of signal from one attitude (level flight in straight runs) to different points in another attitude (the banking in turns). The columns in the exhibit shows:

(1) Column A--change (in db) from the straight run average signal level to the average signal level in the turn.

---

* Jakes, W. C. Microwave Mobile Communications. 1974.

Exhibit 7-15

CLOVERLEAF FLIGHT PATTERN

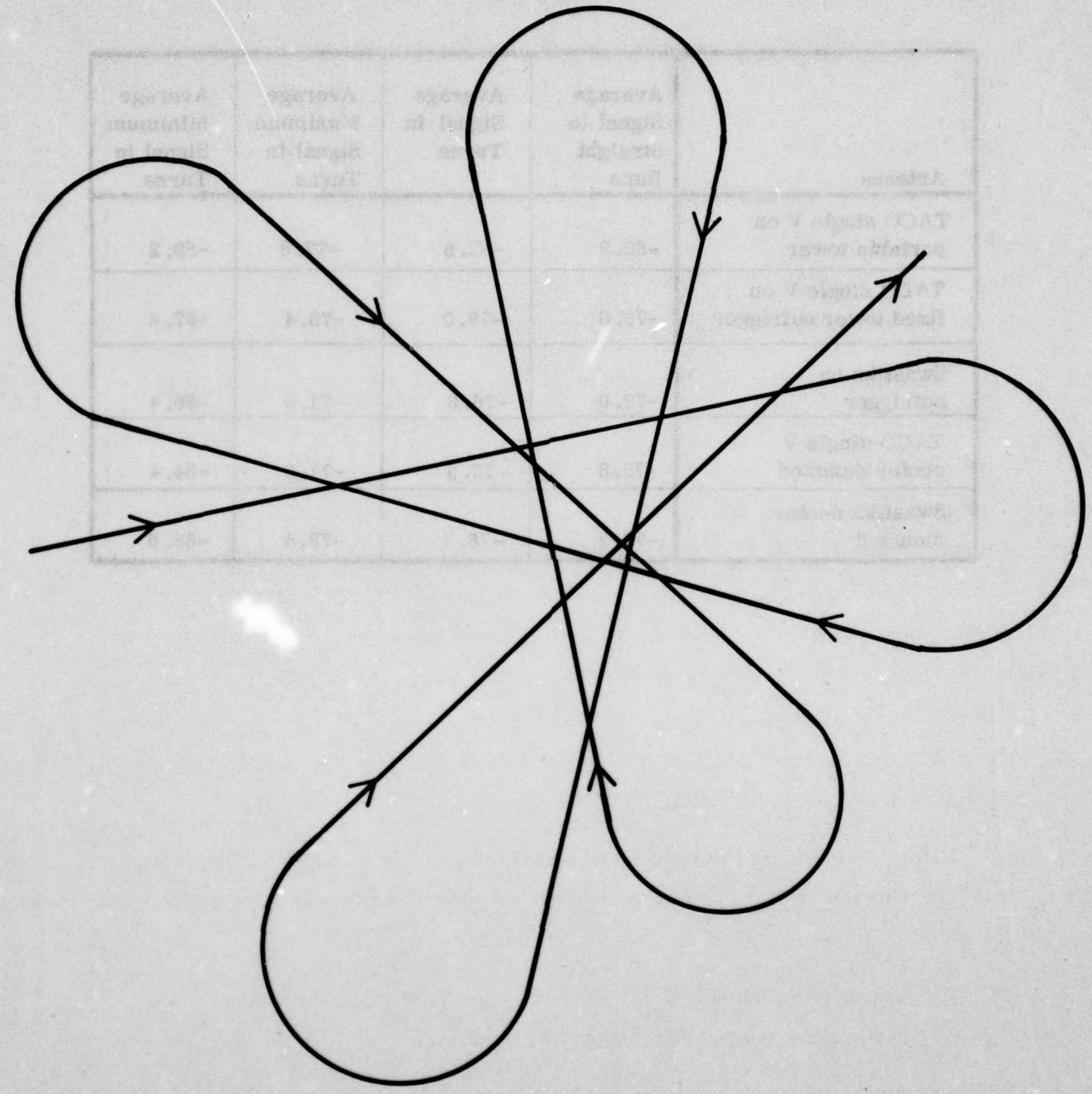


Exhibit 7-16

SIGNAL LEVEL RESULTS FROM CLOVERLEAF PATTERN TEXT

(in dbm)

Antenna	Average Signal in Straight Runs	Average Signal in Turns	Average Maximum Signal in Turns	Average Minimum Signal in Turns
TACO single V on portable tower	-82.2	-82.6	-77.8	-89.2
TACO single V on fixed tower outrigger	-79.6	-79.0	-75.4	-87.6
Swastika on outrigger	-77.0	-76.6	-71.6	-86.4
TACO single V center mounted	-75.8	-75.6	-71.6	-84.4
Swastika center mounted	-76.2	-78.8	-73.4	-88.0

Exhibit 7-17

AVERAGE SIGNAL LEVEL CHANGES

(in db)

Antenna	A*	B*	C*	D*
TACO single V on portable tower	-0.2	5.0	-6.6	11.6
TACO single V on fixed on outrigger	1.0	4.8	-7.8	12.6
Swastika on outrigger	0.8	6.4	-9.4	15.8
TACO single V center mounted	0.8	4.8	-8.4	13.2
Swastika center mounted	-2.2	3.6	-11.4	15.0

*See text.

Exhibit 7-18

EXAMPLE OF STRAIGHT RUN AND TURN INTERVALS

BASED ON CLOVERLEAF RADAR TRACK

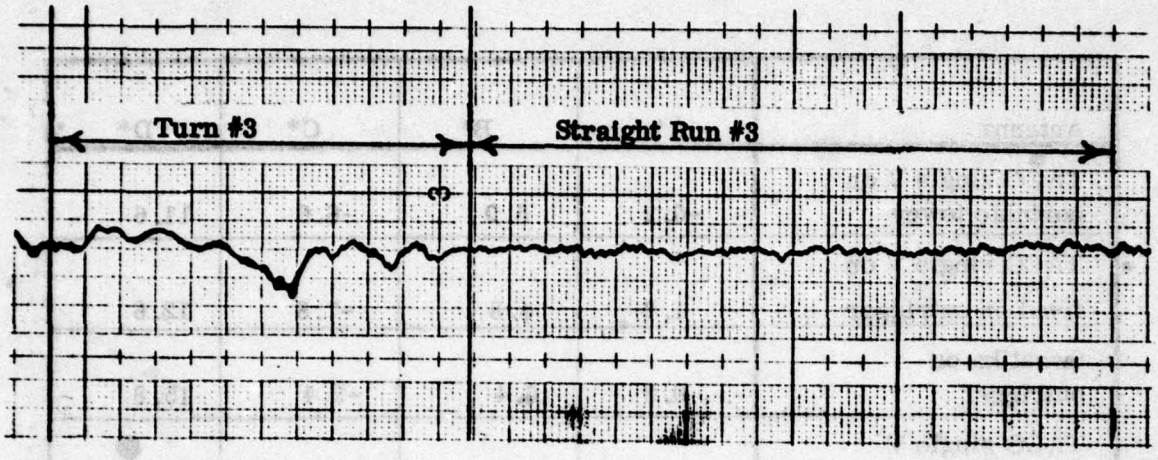


Exhibit 7-19

EXAMPLE SHOWING TURN

NULL INTERVAL

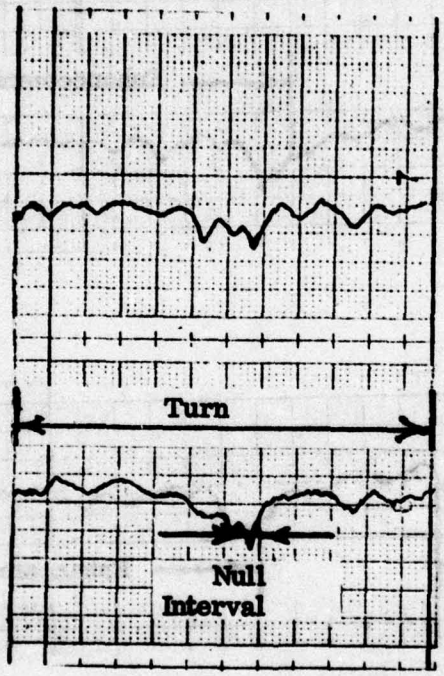
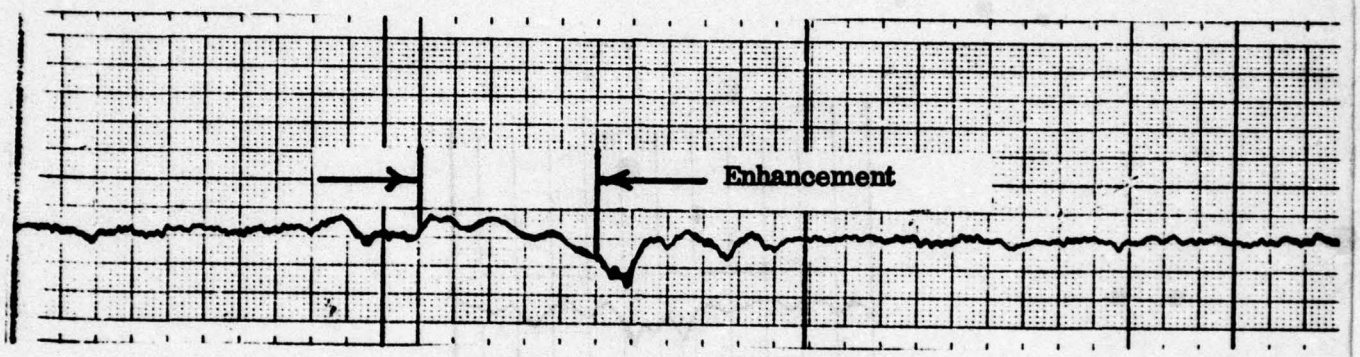
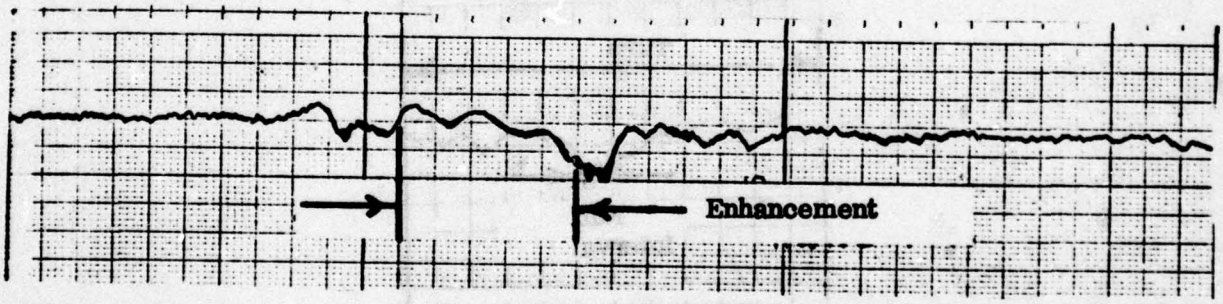


Exhibit 7-20

EXAMPLES SHOWING SIGNAL INCREASE IN TURN





(2) Column B--change from average signal level in straight run to average maximum signal in the turn.

(3) Column C--change from average signal level in straight run to average minimum signal level in turn.

(4) Column D--average dynamic range of signal in turn.

From this exhibit, we can see that in most cases the signal remains relatively constant through turns. The only significant exception here is the change of -2.2 db shown by the center-mounted swasktika. We can also see that in terms of signal enhancement in the turn all three TACO signal VHF dipoles perform almost identically (as expected).

Another fact that is evident from the data is that the swastika antennas show no significant advantage (as expected, since they are circularly polarized) over the dipoles as the aircraft goes into turns (with the possible exception of the swastika on the outrigger having the largest average signal enhancement). It is possible that the swastika is not truly circularly polarized but, in fact, elliptically polarized with an emphasis of the vertical component. Interestingly, the swastikas also suffer the worst signal change from the straight run to the turn null.

As to signal levels (Exhibit 7-16), again the TACO single VHF antenna mounted in the center of the tower had the best performance on all counts. None of the other configurations was clearly the next best performer. In fact, ranking the remaining four antennas on the different signal level criteria (in descending order, best to worst) yields:

(1) Average signal in straight runs
   (a) Swastika center mounted
   (b) Swastika on outrigger
   (c) TACO single VHF on outrigger
   (d) TACO single VHF on portable tower

(2) Average signal in turns
   (a) Swastika on outrigger
   (b) Swastika center mounted

(c) TACO single VHF on outrigger

(d) TACO single VHF a portable tower

(3) Average maximum signal in turns

(a) Swastika on outrigger

(b) Swastika center mounted

(c) TACO single VHF on outrigger

(d) TACO single VHF on portable tower

(4) Average minimum single in turns

(a) Swastika on outrigger

(b) TACO single VHF on outrigger

(c) Swastika center mounted

(d) TACO single VHF on portable tower

Again, the antenna on the portable tower had the worst performance because of the reasons outlined above (Experiment No. 1).

7.6.3 Experiment No. 3

This experiment, performed in two parts (i.e., with two different flight tests), had several objectives:

(1) The comparative observation of two antenna configurations in a quasi-operational environment. The standard FAA VHF transmit-receive antenna system pair (in its operational environment accompanied by two UHF discones) was compared to two TACO single VHF dipoles on a fixed tower as an alternate VHF antenna configuration.

(2) The simultaneous observation of several gain and stacked antennas in close proximity (i.e., on a single fixed tower). The main purpose here was to observe the relative performance of the antennas and not to do an in-depth characterization of the proximity effects of the antennas (unless severe degradation was evident).

(3) The overall comparison of all the antennas in this experiment among each other.

The configurations used for the two flight tests are shown in Exhibits 7-21 and 7-22. As indicated in Exhibit 7-21, only the upper antenna elements of the stacked antennas were utilized during the experiments. By doing this, a comparison could be made examining the isolation* provided by vertical extension using the stacked configuration, in contrast to the isolation provided by using a simple nonmetallic tube as an extension (this latter was done to mount the TACO single V dipoles on fixed towers in all the experiments). A full 360-degrees orbit was flown at a range of 25 nm and an altitude of 4,000 feet.

The orbital plots from these flight tests are shown in Exhibits B-6 through B-15, and the performance tables for both experiments are shown in Exhibit 7-23. Also, Exhibits 7-24 and 7-25 show the signal level performance of the antennas by quadrant for more detailed comparisons.

As expected, the two gain antennas were the best overall performers, with the Phelps Dodge gain antenna having the highest level of -65.9 dbm, 1.5 db more signal than the other gain antenna, the TACO gain (which had a mean signal level of -67.4 dbm). Note that from a theoretical operational standpoint, based on the results, the Phelps Dodge gain antenna has a gain of essentially 0 dbi since it is almost equal to the free space loss value (-65.36 dbm) at 25 nm.

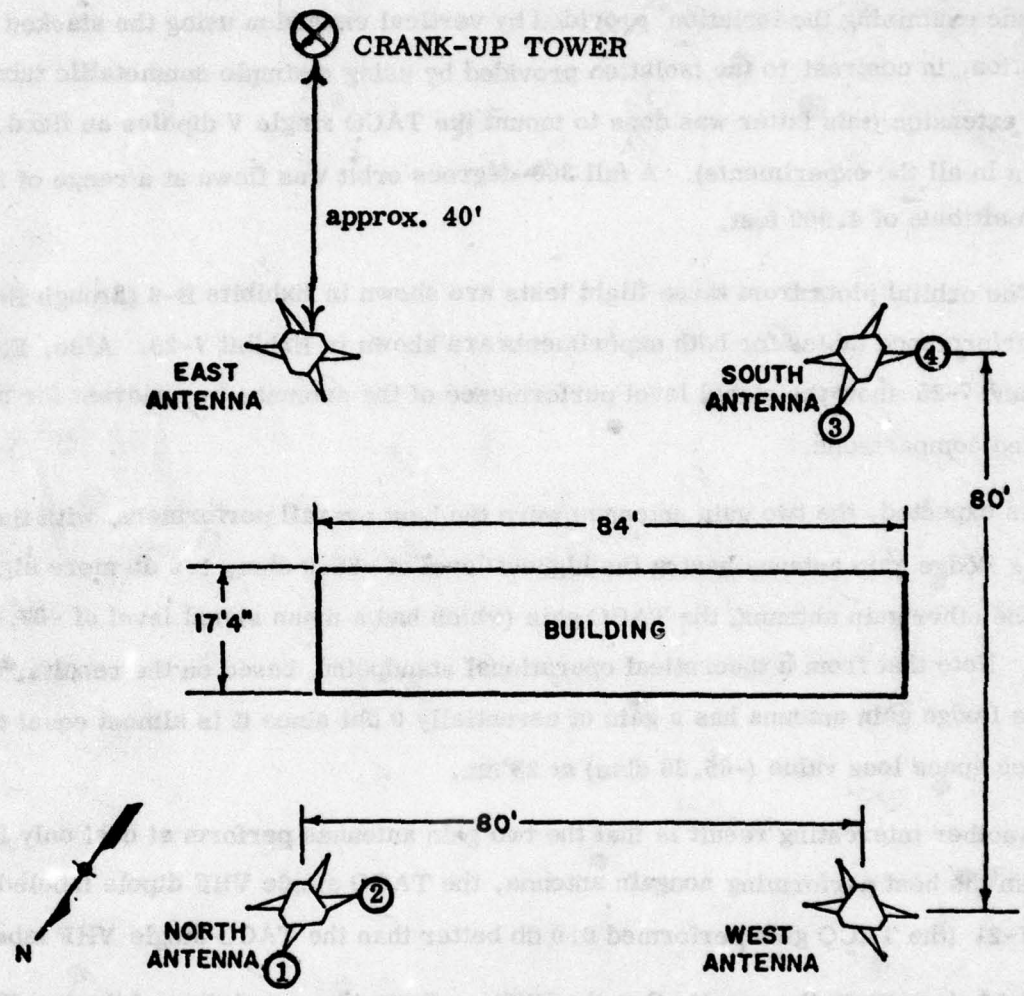
Another interesting result is that the two gain antennas perform at best only 2.4 db better than the best performing nongain antenna, the TACO single VHF dipole labeled D in Exhibit 7-21 (the TACO gain performed 0.9 db better than the TACO single VHF labeled D).

It is clear from the results that the VHF configuration consisting of the two TACO single VHF dipoles (Exhibit 7-21) performed significantly better (at worst 3.7 db better, at best 8.7 db) than the standard FAA combination of the swastika and the coaxial dipole. Moreover, in addition to this better performance at a distance from the site, the swastika and, especially, the coaxial dipole have a severely degraded performance when the aircraft is close to the site (within a range of 5 nm of the site.) This degradation is clearly exhibited in Exhibit 7-26 where the TACO single VHF dipole performance

*The isolation referred to here is the added isolation provided by vertical extension not the built in isolation of stacked configurations alluded to in section 6.2.3.

Exhibit 7-21

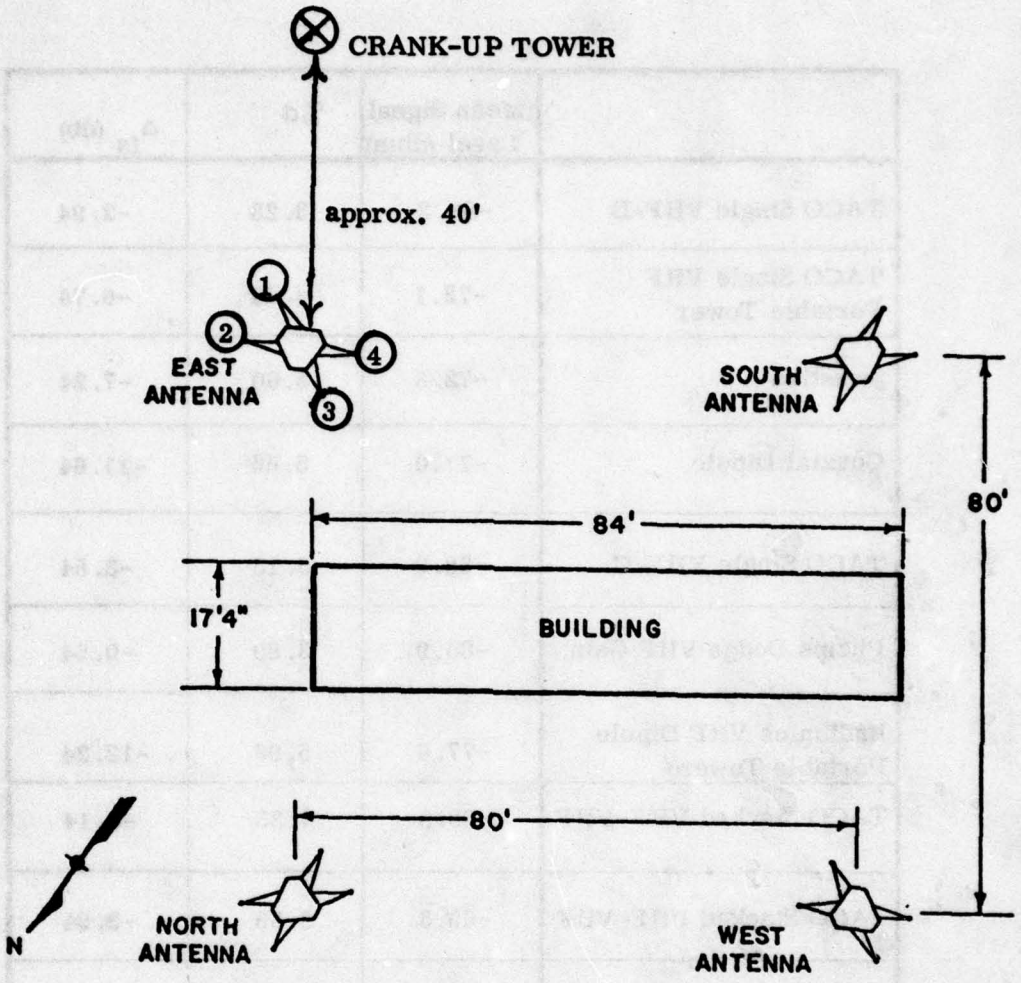
CONFIGURATION FOR FIRST HALF OF EXPERIMENT 3



North Tower #1 Swastika
North Tower #2 Coaxial Dipole
South Tower #3 TACO D-2216
South Tower #4 TACO D-2216

Exhibit 7-22

CONFIGURATION FOR SECOND HALF OF EXPERIMENT 3



East Tower #1 TACO D-2212 (V- Ⓥ)

East Tower #2 TACO D-2213 (U- Ⓥ)

East Tower #3 TACO D-2261 V-Gain

East Tower #4 Phelps Dodge-220

Crank-up Tower Radionics 5731

Exhibit 7-23

RESULTS OF EXPERIMENT NO. 3

	Mean Signal Level (dbm)	%d	Δ_{fs} (db)
TACO Single VHF-D	-68.3	3.23	-2.94
TACO Single VHF Portable Tower	-72.1	4.73	-6.74
Swastika	-72.6	5.00	-7.24
Coaxial Dipole	-77.0	5.66	-11.64
TACO Single VHF-C	-68.9	3.15	-3.54
Phelps Dodge VHF Gain	-65.9	3.89	-0.54
Radionics VHF Dipole Portable Tower	-77.6	5.96	-12.24
TACO Stacked VHF-VHF	-68.5	4.35	-3.14
TACO Stacked UHF-VHF	-69.3	3.39	-3.94
TACO VHF Gain	-67.4	3.58	-2.04

Exhibit 7-24

MEAN SIGNAL LEVEL BY QUADRANTS
FOR ANTENNAS IN EXPERIMENT NO. 3
(in dbm)

Antenna / Quadrant	D-TACO Single VHF	TACO Single VHF Portable Tower	Swastika	Coaxial Dipole	C-TACO Single VHF
1st Quadrant	70.0	73.3	75.4	74.4	69.7
2nd Quadrant	67.9	71.2	72.0	80.5	68.0
3rd Quadrant	66.3	68.6	68.2	81.9	67.1
4th Quadrant	69.0	75.1	74.8	71.6	70.6
Full Orbit	68.3	72.1	72.6	77.0	68.9

Exhibit 7-25

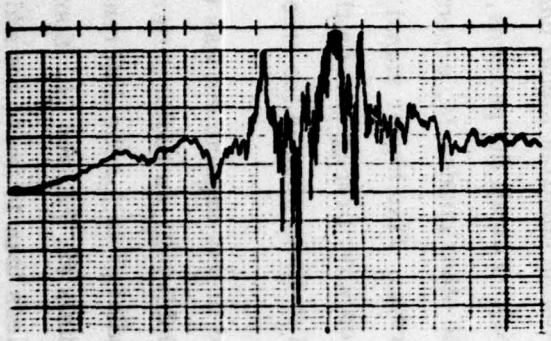
MEAN SIGNAL LEVEL BY QUADRANTS
FOR ANTENNAS IN EXPERIMENT NO. 3
(in dbm)

Antenna / Quadrant	Phelps Dodge V-Gain	Radionics VHF Portable Tower	TACO (V - Ⓥ)	TACO (U - Ⓥ)	TACO V-Gain
1st Quadrant	68.0	82.3	70.9	71.9	68.7
2nd Quadrant	68.1	77.5	67.8	69.0	68 5
3rd Quadrant	62.4	71.7	65.6	66.1	64.1
4th Quadrant	65.9	77.6	68.5	69.3	67.4
Full Orbit	65.9	77.6	68.5	69.3	67.4

Exhibit 7-26

BEHAVIOR OF ANTENNAS CLOSE (<5 nm) TO SITE

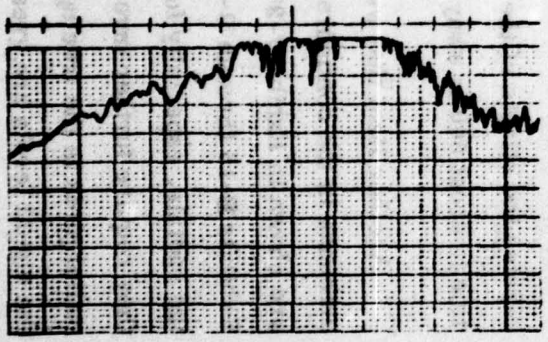
a. Coaxial Dipole



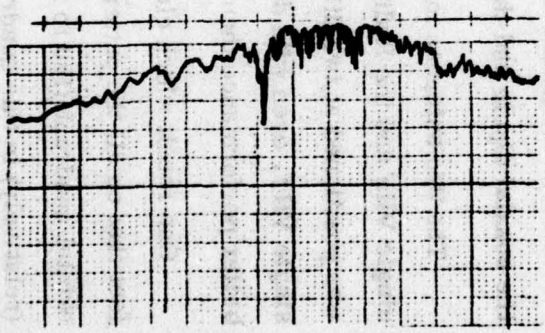
b. Swastika



c. TACO Single V-D



d. TACO Single V-C



e. TACO Single V Portable Tower



is shown for comparison. Some of the nulls of the coaxial dipole are as deep as -110 dbm, well below the sensitivity of current FAA receiving equipment.

The stacked antennas performed as expected. The TACO VHF-UHF stack (the upper antenna was tested) performed roughly equal to the single VHF dipoles. This is because the length of the lower antenna in the stack has essentially the same length as the four foot non-metallic mount used with the single VHF dipoles. The UHF-VHF stack signal level was correspondingly smaller, because the UHF antenna in the lower position is shorter (antenna size is inversely proportional to frequency) so that the vertical extension is less.

Most of the patterns were relatively smooth (based on % d) except the swastika, the coaxial dipole and the Radionics dipole mounted on the portable tower.

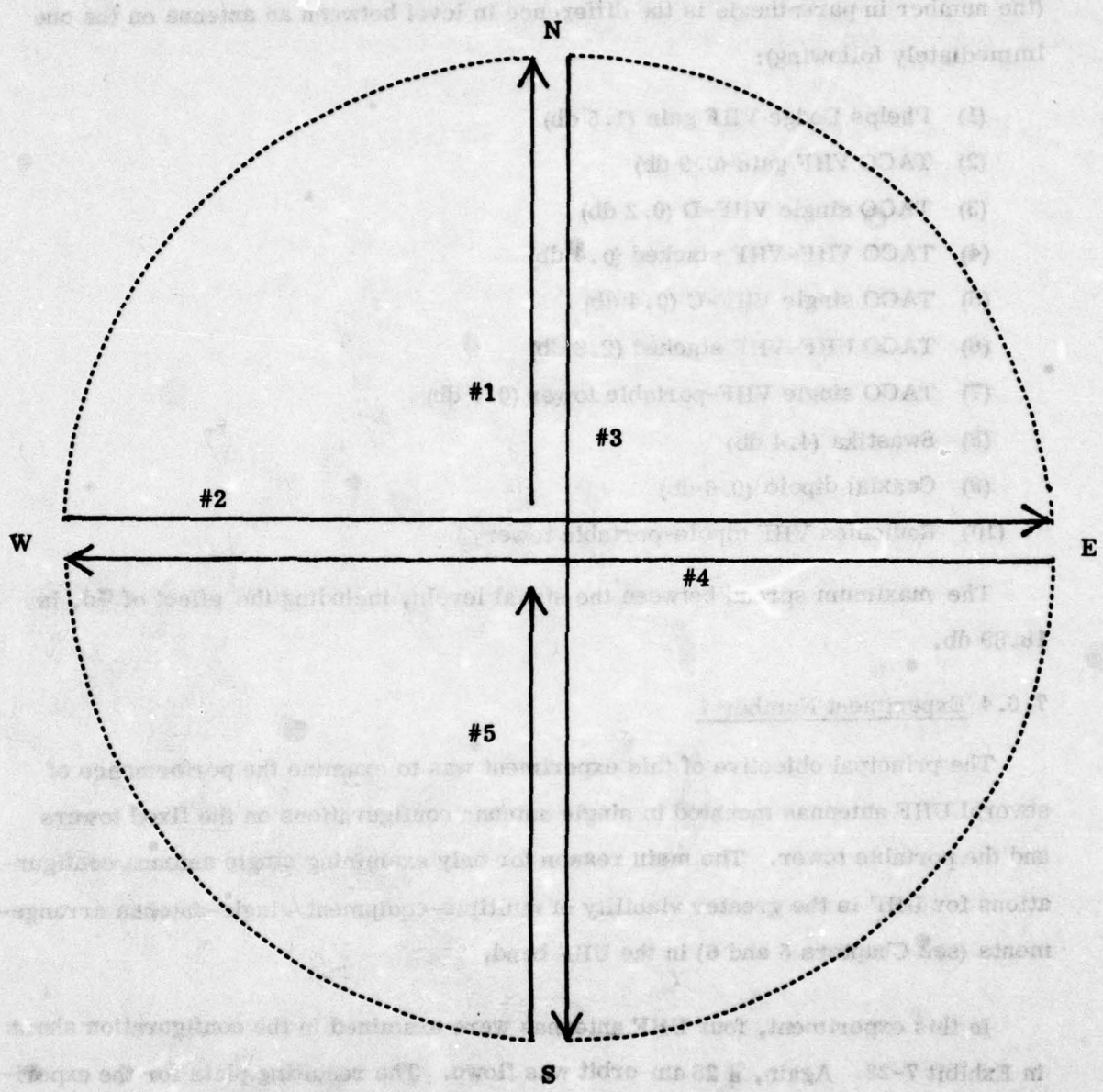
The two antennas mounted on the portable tower in the two flight tests (the TACO single VHF and the Radionics VHF dipole) are not directly comparable since the tower was positioned at two different heights for the two flight tests. However, the TACO single VHF, even with degradation due to mounting on the portable tower, exhibited better performance than the swastika and the coaxial dipole.

One result which clearly indicated the effects of the test environment was the fact that on all the patterns there was an apparent signal enhancement in the southwest orbital quadrant (180 to 270 degrees). For all the patterns, there is more signal (relatively) in this quadrant than the other quadrants, especially the quadrants from 270 to 360 degrees and 0 to 90 degrees. This higher signal level starkly demonstrates the effects of the tree line on wave propagation (in the SW quadrant, the tree line is about 500 m away compared to about 80 m in the other cases).

Another item that was explored in this experiment was the performance of the antennas in the configuration of Exhibit 7-21 on radial patterns. The radials flown are shown in Exhibit 7-27. The radial plots for the different antennas are shown in Exhibits B-16 through B-18 for radials #2, #2, and #4. Some of the unusual behavior of the radials, especially for ranges less than 10 nm is not addressed here because of they require further investigation that was not pursued. Also included on some radial plots is the free space radial for comparison. We see that at certain ranges the signal levels are greater than the free space level. This is expected from theory,

Exhibit 7-27

RADIAL PATTERNS FLOWN



since the antennas for which this occurs are dipoles with roughly a 2 db gain over free space. The range at which this increase occurs can also be determined by examining the vertical lobing structure of the antennas (see Appendix A).

A listing of the antennas based on mean signal level over the orbit is as follows (the number in parenthesis is the difference in level between an antenna on the one immediately following):

(1) Phelps Dodge VHF gain (1.5 db)
(2) TACO VHF gain (0.9 db)
(3) TACO single VHF-D (0.2 db)
(4) TACO VHF-VHF stacked (0.4 db)
(5) TACO single VHF-C (0.4 db)
(6) TACO UHF-VHF stacked (2.8 db)
(7) TACO single VHF-portable tower (0.5 db)
(8) Swastika (4.4 db)
(9) Coaxial dipole (0.6 db)
(10) Radionics VHF dipole-portable tower

The maximum spread between the signal levels, including the effect of %d, is 18.89 db.

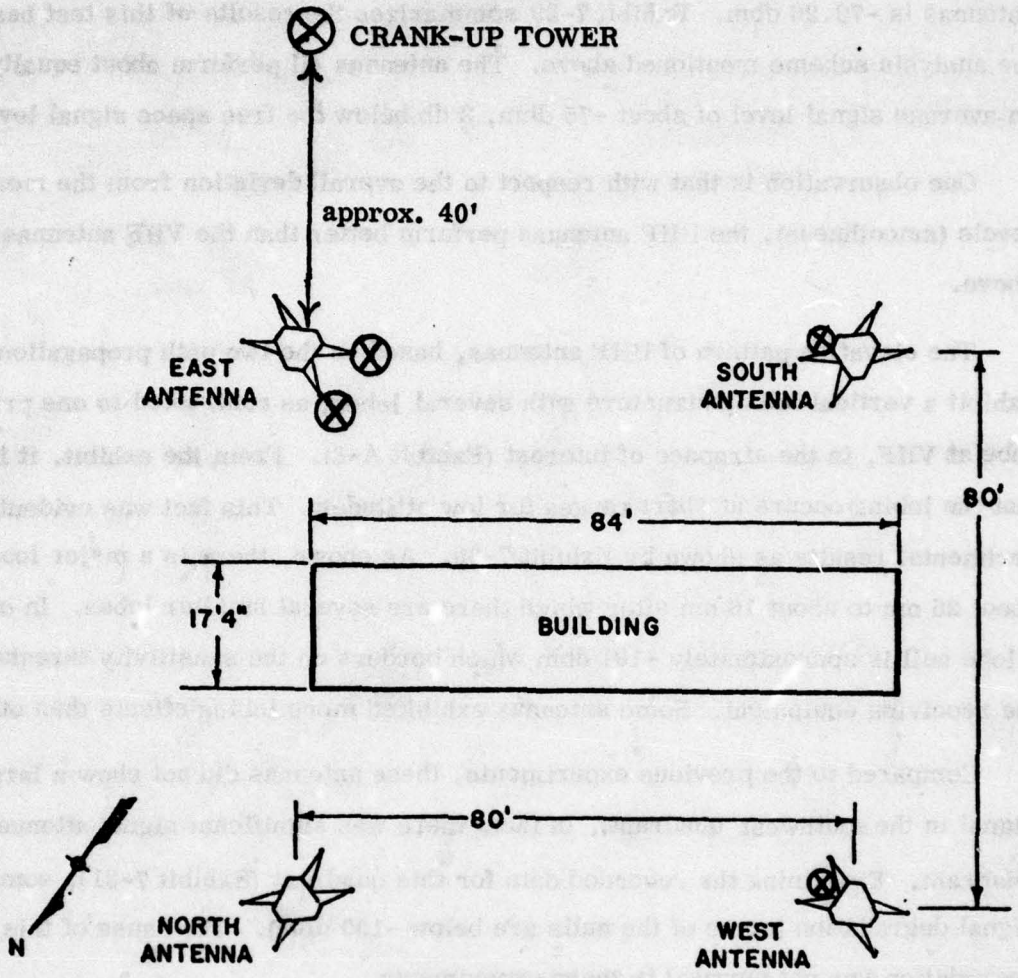
7.6.4 Experiment Number 4

The principal objective of this experiment was to examine the performance of several UHF antennas mounted in single antenna configurations on the fixed towers and the portable tower. The main reason for only examining single antenna configurations for UHF is the greater viability of multiple-equipment/single-antenna arrangements (see Chapters 5 and 6) in the UHF band.

In this experiment, four UHF antennas were examined in the configuration shown in Exhibit 7-28. Again, a 25 nm orbit was flown. The resulting plots for the experiment are shown in Exhibits B-19 through B-22. The exhibit for the pattern of the DPV-22 antenna shows results for only a half-orbit, because the channel recording the data for this antenna failed. The results shown were collected in a manual backup recording scheme (i.e., the results were collected manually at five-minute intervals from

Exhibit 7-28

EXPERIMENT NO. 4 ANTENNA CONFIGURATIONS



West Tower	Collins UHF	R-361-SN	1302	1
South Tower	DPV-22	R-361-SN	4623	3
East Tower #3	TACO-2262	R367-SN	120	7
East Tower #4	Radionics	5831 R-361	273	8
Crank-Up Tower	TACO D-2217	Spectrum Analyzer*		

the spectrum analyzer, which was connected to the DPV-22.) The frequency of operation for this experiment was 279.2 MHz. At this frequency, the signal level corresponding to +40 dbm transmitted power, no system loss (only free space losses) and isotropic antennas is -72.26 dbm. Exhibit 7-29 summarizes the results of this test based on the analysis scheme mentioned above. The antennas all perform about equally with an average signal level of about -75 dbm, 3 db below the free space signal level.

One observation is that with respect to the overall deviation from the mean signal levels (smoothness), the UHF antennas perform better than the VHF antennas examined above.

The elevation pattern of UHF antennas, based on the two path propagation model, exhibit a vertical lobing structure with several lobes, as contrasted to one principal lobe at VHF, in the airspace of interest (Exhibit A-8). From the exhibit, it is evident that the lobing occurs at short ranges for low attitudes. This fact was evident in the experimental results as shown by Exhibit 7-30. As shown, there is a major lobe from about 25 nm to about 16 nm after which there are several smaller lobes. In one case, a lobe null is approximately -101 dbm which borders on the sensitivity threshold of the receiving equipment. Some antennas exhibited more lobing effects than others.

Compared to the previous experiments, these antennas did not show a larger signal in the southwest quadrant. In fact, there was significant signal attenuation in this quadrant. Examining the recorded data for this quadrant (Exhibit 7-31), some severe signal degradation (some of the nulls are below -100 dbm). The cause of this degradation was not pursued in these experiments.

7.6.5 Experiment Number 5

In this experiment, the signal improvement obtained by adding vertical extension to the antennas by mounting them on metallic or nonmetallic tubing is examined and compared to the case of the antenna mounted level at the tower railing height on the swing-arm boom (horizontal extension).

Exhibit 7-29

RESULTS OF EXPERIMENT NO. 4

	Mean Signal (dbm)	%d	Δfs
Collins UHF	-74.6	3.26	-2.34
Radionics UHF	-75.9	3.13	-3.64
TACO UHF	-74.7	3.62	-2.44
DPV-22 UHF	-75.5* (-73.0#)	3.9	-3.26 (-0.74)

*Using data as recorded on Texscan spectrum analyzer.

Using data "corrected" by post (test) calculation of Texscan display.

Exhibit 7-30

EXPERIMENTAL RESULTS: ANTENNA LOBING EFFECTS

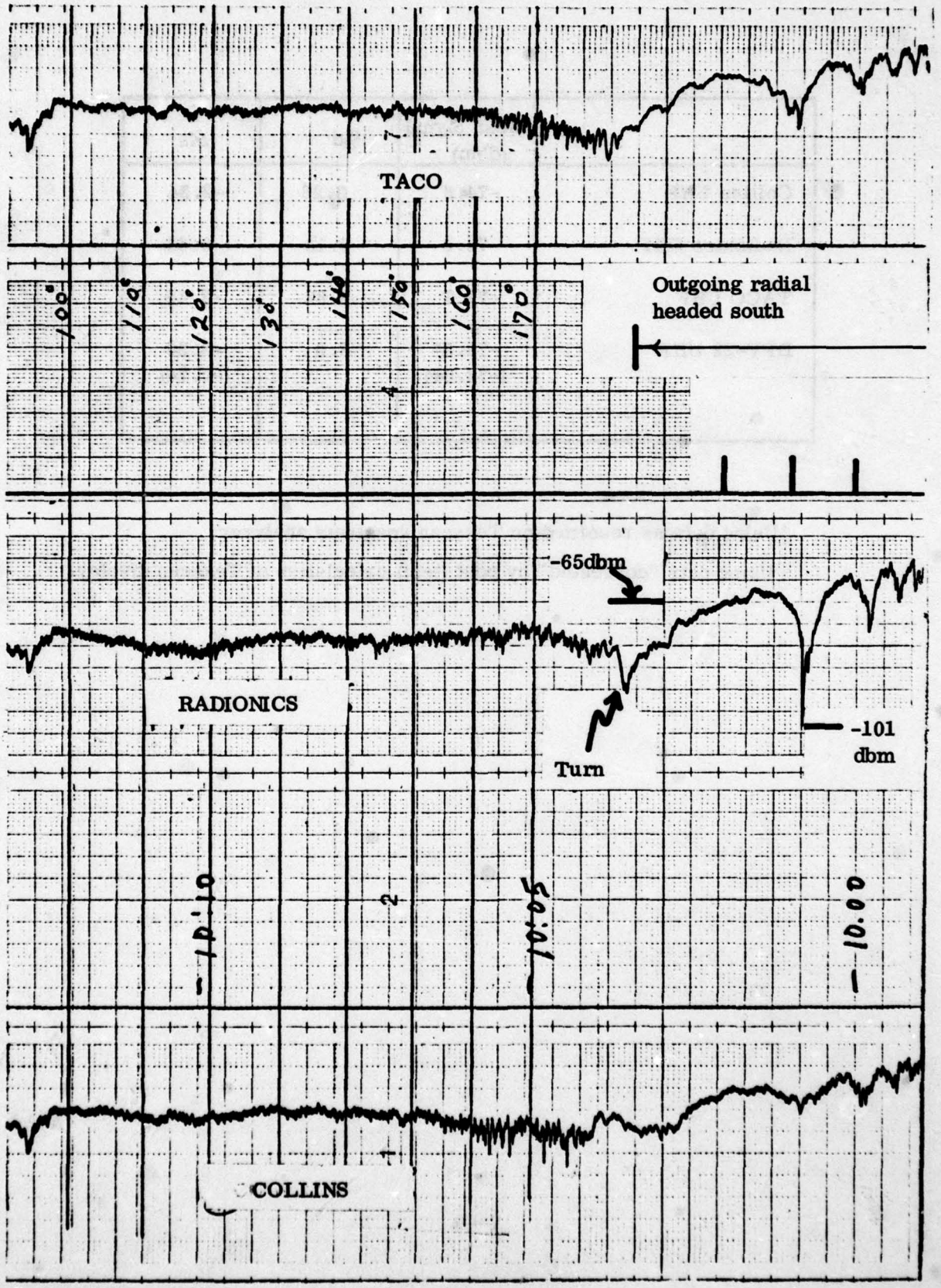
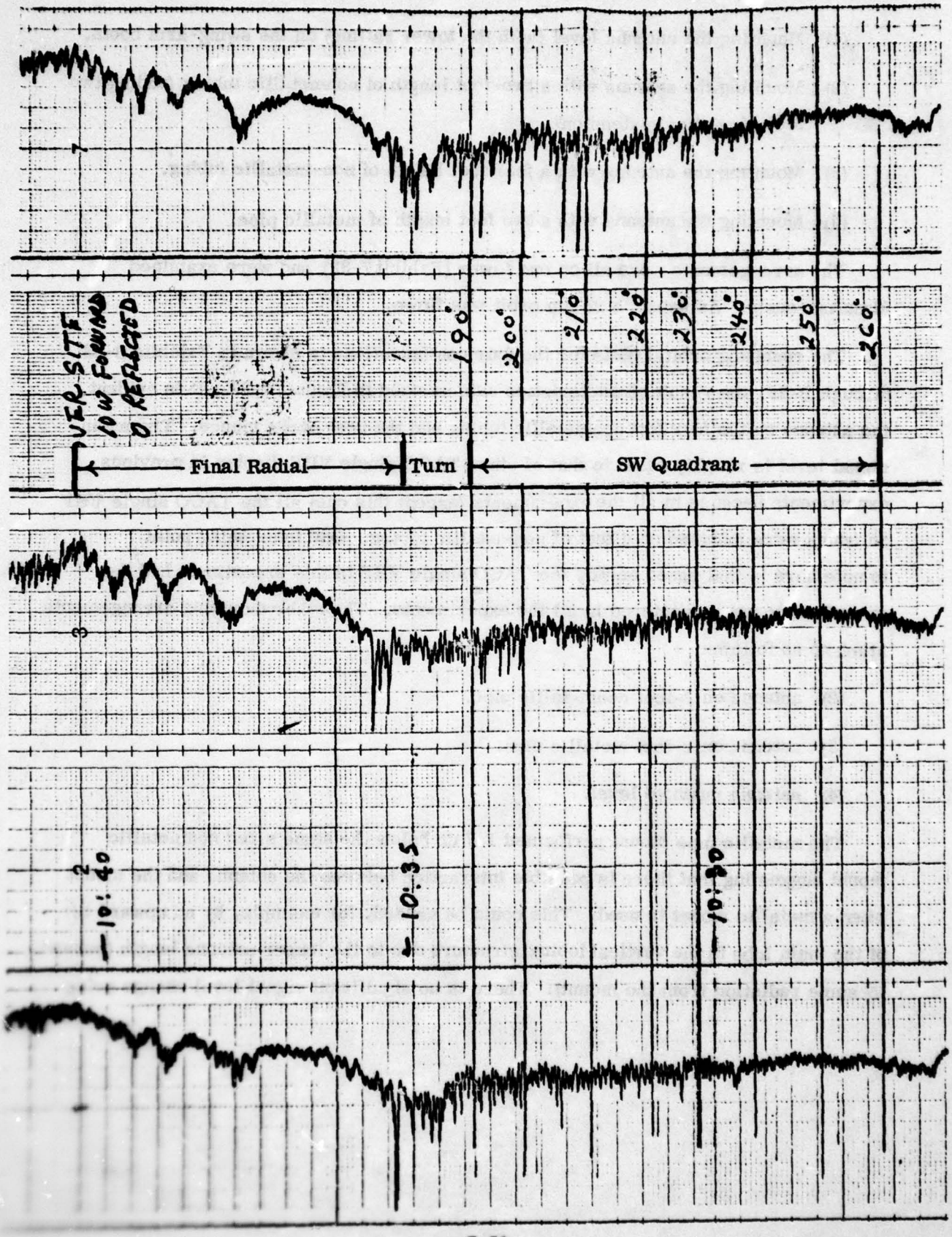


Exhibit 7-31

RECORDED DATA FOR SOUTHWEST QUADRANT



The antenna in all cases (for consistency) was the TACO single VHF dipole. Four mounting arrangements were examined. They were:

(1) Mounting the antenna level (with the tower railing) on the swing-arm boom.

(2) Mounting the antenna with a two-foot length of nonmetallic tubing (adding two feet of vertical extension).

(3) Mounting the antenna with a four foot length of non-metallic tubing.

(4) Mounting the antenna with a two foot length of metallic pipe.

The arrangements were all on one tower (Exhibit 7-32) and were examined simultaneously. As usual, a 25 nm orbit was flown.

The resulting orbital plots for the four configurations is shown in Exhibits B-23 through B-26, the result characteristics summarized in Exhibit 7-33. It is evident the antenna on the four foot nonmetallic tubing had the best performance. The mean signal level is roughly equal to that of other TACO single VHF dipoles in previous experiments because in all the experiments (except this one) all the TACO single VHF antennas were mounted on 4 feet of nonmetallic tubing. One interesting point to note here is that based on %d, the TACO single VHF in this experiment had the smoothest curve encountered in all the experiments. The other mounting arrangements stack up as follows:

(2) antenna on 2-foot nonmetallic pipe.

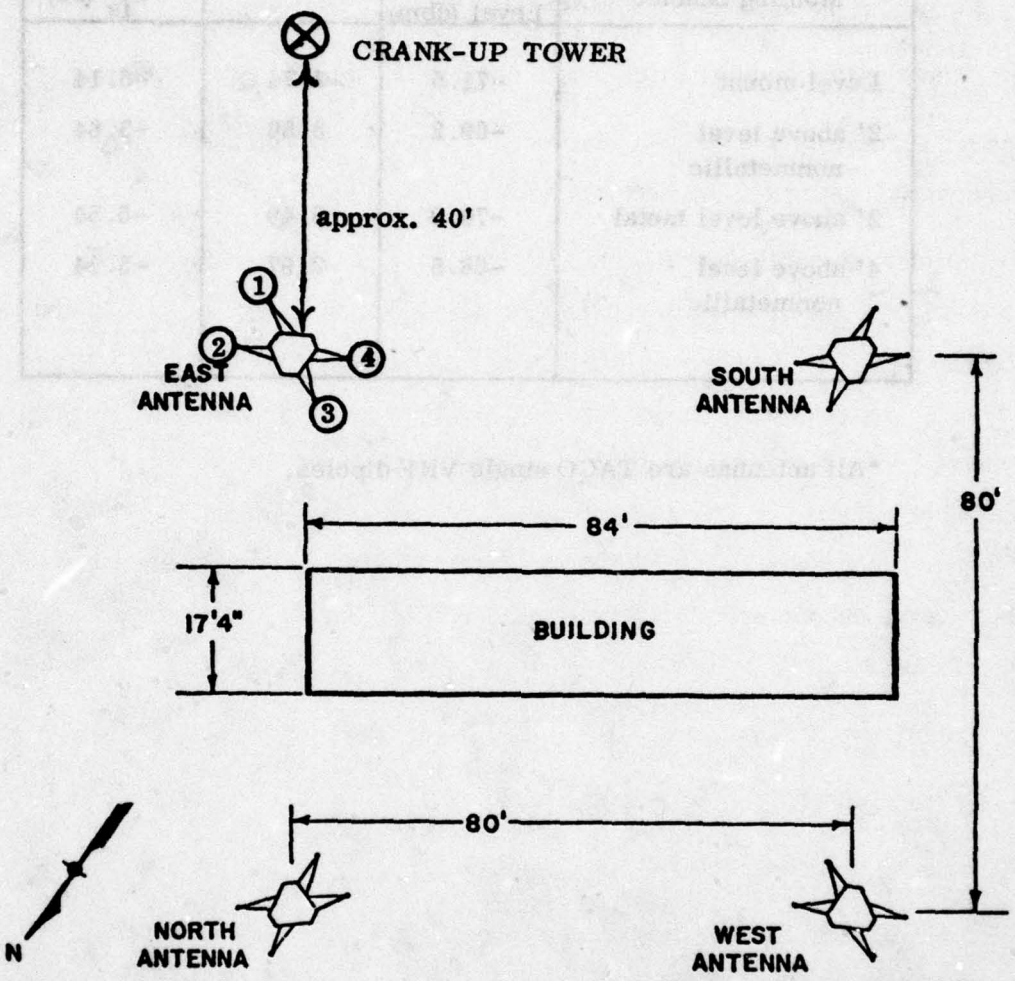
(3) antenna on 2-foot metallic pipe.

(4) antenna mounted level.

The metallic pipe mount performed 1.7 db below the same sized nonmetallic mount suggesting that there is possible interaction between the antenna and the mount when a metallic mount is used. This could be caused, for example, by an upward tilt of the main lobe in the vertical lobing structure due to the longer antenna length (caused by some radiation from the mount). There is no significant signal level change going

Exhibit 7-32

ANTENNA CONFIGURATION FOR EXPERIMENT 5



1. TACO D-2216 at Mount Level
2. TACO D-2216 2' above Mount Nonmetalic Pipe
3. TACO D-2216 2' above Mount Metal Pipe
4. TACO D-2216 4' above Mount Nonmetalic Pipe
5. Radionics on Crank-Up Tower 45'

Exhibit 7-33

RESULTS FOR EXPERIMENT NO. 5

Mouting Scheme*	Mean Signal Level (dbm)		Δ_{fs} (db)
Level mount	-71.5	4.74	-6.14
2' above level nonmetallic	-69.2	3.56	-3.84
2' above level metal	-70.9	3.49	-5.54
4' above level nonmetallic	-68.5	2.97	-3.14

*All antennas are TACO single VHF dipoles.

from a two-foot nonmetal mount to a four-foot nonmetal mount. A 100 percent change in length only occasioned a 1.02 percent (.7 db) signal level change. However, the smoothness of the pattern may makes the four-foot nonmetal vertical extension worthwhile.

The results show a 3 db improvement in signal level by mounting the antenna on a four foot nonmetal vertical extendor compared to mounting the antenna level with the tower railing.

7.7 CONCLUSIONS

Based on the results of the flight experimentation, the following inferences can be drawn:

(1) Mounting antennas in the center of the towers may offer significant advantages in terms of both signal level and reduced horizontal pattern distortion. These considerations are especially important in considering the tradeoffs for the use of single antenna configurations utilizing multiple equipment configurations (e.g., multicouplers, combiners). However, the results are not conclusive enough. Further testing should be done on the effect of platform geometry and the use of nonmetallic platforms on the resulting patterns.

(2) Adding vertical extension to the antennas above the tower railing level also provides advantages with respect to signal level and reduced pattern distortion. The extension may not be necessary if the distortion is caused by the metal tower platform for, in that case, a solution would be to use nonmetallic material for the tower platform. Moreover, if the distortion is caused by proximity to other antennas, the vertical extension benefits are lost once multiple antennas, all extended, are mounted on the same platform.

One of the items requiring further investigation here is the optimum length of vertical extension. The small difference in signal level between a two-foot nonmetal extender and one of four feet suggests that maybe only three feet is necessary to obtain the improved per-

formance; of course, the above applies to nonmetallic extenders. Finally, another area requiring further study is the effect of adjacent towers on the horizontal patterns.

(3) The antennas tested do not seem to be unduly affected by aircraft attitude. The average signal level remained essentially constant before, during, and after turning maneuvers. However, the signal level showed a wide fluctuation over a short period during the turns between a null, at the apex of the turn, followed by signal level enhancement immediately after coming out the turn. Some of the nulls bordered on the sensitivity threshold of the receiving equipment. An area that requires further investigation here is some systematic characterization of the effect of airborne antenna systems on the signal levels. In particular, the patterns of airborne antennas as a function of attitude.

(4) The swastika/coaxial dipole VHF configuration was clearly outperformed by the two TACO alternate configuration.

(5) The gain antennas tested showed no significant advantage over the better performing nongain antennas in terms of signal level and essentially equalled the performance of the nongain antennas in terms of omnidirectionality. In addition, the size/cost of trade-offs definitely favor the use of the nongain antennas.

(6) The UHF antennas tested all perform roughly equal so that trade-offs between them have to be made on the basis of other parameters. For example, in addition to physical characteristics parameter (e.g., length and weight) trade-offs, comparison could be made on the basis of vertical lobing structure.

Some of the conclusions above are necessarily tentative since resource availability limited the extent and sample size in the various tests. However, the results offer some empirical sense of the solution to the problems of upgrading and optimizing antenna systems.

8

ANTENNA SYSTEM CONFIGURATIONS FOR EN ROUTE APPLICATIONS

8.1 GENERAL

The antennas employed and their utilization in multiple radio channel activity depend upon the characteristics and mode of operation of the air/ground radio system. The specific performance of a single antenna must be placed within the context of its application. The preceding sections on analysis and experimentation have considered the various parameters concerned with FAA air/ground radio operations in order to better develop an effective approach to antenna system configurations that will respond to current and future requirements for performance and growth of air activity.

The results derived from this project's efforts can be expressed in four principal areas:

(1) Radio Coverage

(2) Colocation

(3) Antenna Systems

(4) Multichannel Configurations

8.2 RADIO COVERAGE

To provide radio coverage with a propagation reliability consistent with air/ground radio system availability, it is necessary to employ redundant coverage over each airspace sector. The redundant coverage is provided by a technique similar to that of space diversity wherein the radio facility locations are dispersed to gain independence of propagation conditions.

Three types of radio coverage exist that are required to respond to FAA ATC operations.

(1) Primary Coverage

(2) Redundant or Secondary Coverage

(3) Gap Filler Coverage

Primary coverage is obtained with use of a single radio facility (RCAG) that is located to provide the maximum obtainable line of sight coverage over a specific air space sector, as shown in Exhibit 8-1. As noted in previous sections, the primary coverage often falls short of filling the entire sector so that gaps in coverage continue to exist due to terrain or other problems. This is illustrated in Exhibit 8-1, where the dotted area represents a deficiency in the coverage.

Redundant or secondary coverage is that obtained with use of one or more radio facilities that are located in the areas and that offer some degree of radio coverage over the primary coverage air sector. This situation is shown in Exhibit 8-2, which illustrates two adjacent sectors with their radio facilities. Facility B (in sector B) provides sufficient radio coverage to supply redundant coverage over a substantial portion of sector A. The intersection of coverage contours A and B represents the redundant coverage and this is shown in Exhibit 8-2 as a shaded area. The use of additional coverage from either sector C or sector D or both would complete the redundant coverage for sector A.

Gap filler coverage is that provided by use of one or more radio facilities that are located in adjacent sectors and that offer coverage not obtainable at the primary radio facility. Exhibit 8-2 shows that coverage contour B provides coverage to fill the gaps in sector A--the gap filler coverage is shown as the cross-hatched region. Redundant gap filler coverage may in many instances be available with the use of additional adjacent sector radio, e.g., sectors C or D in Exhibit 8-2.

Using this approach, the radio channel availability can be made consistent with other segments of the air/ground system. The added reliability does not come free as multiple site operations are required to operate in this mode. However, it would be expected that a controller might operate 95 to 99 percent of the time with the

Exhibit 8-1

PRIMARY COVERAGE SECTOR A

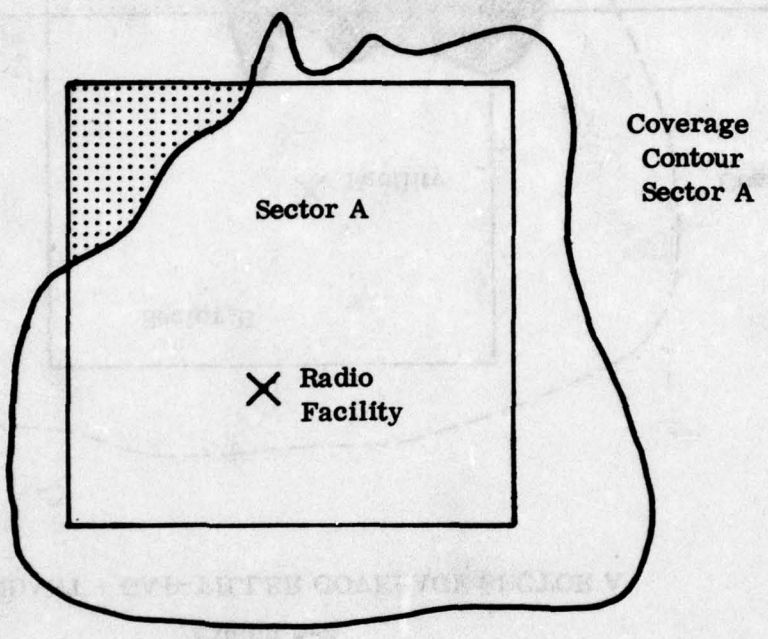
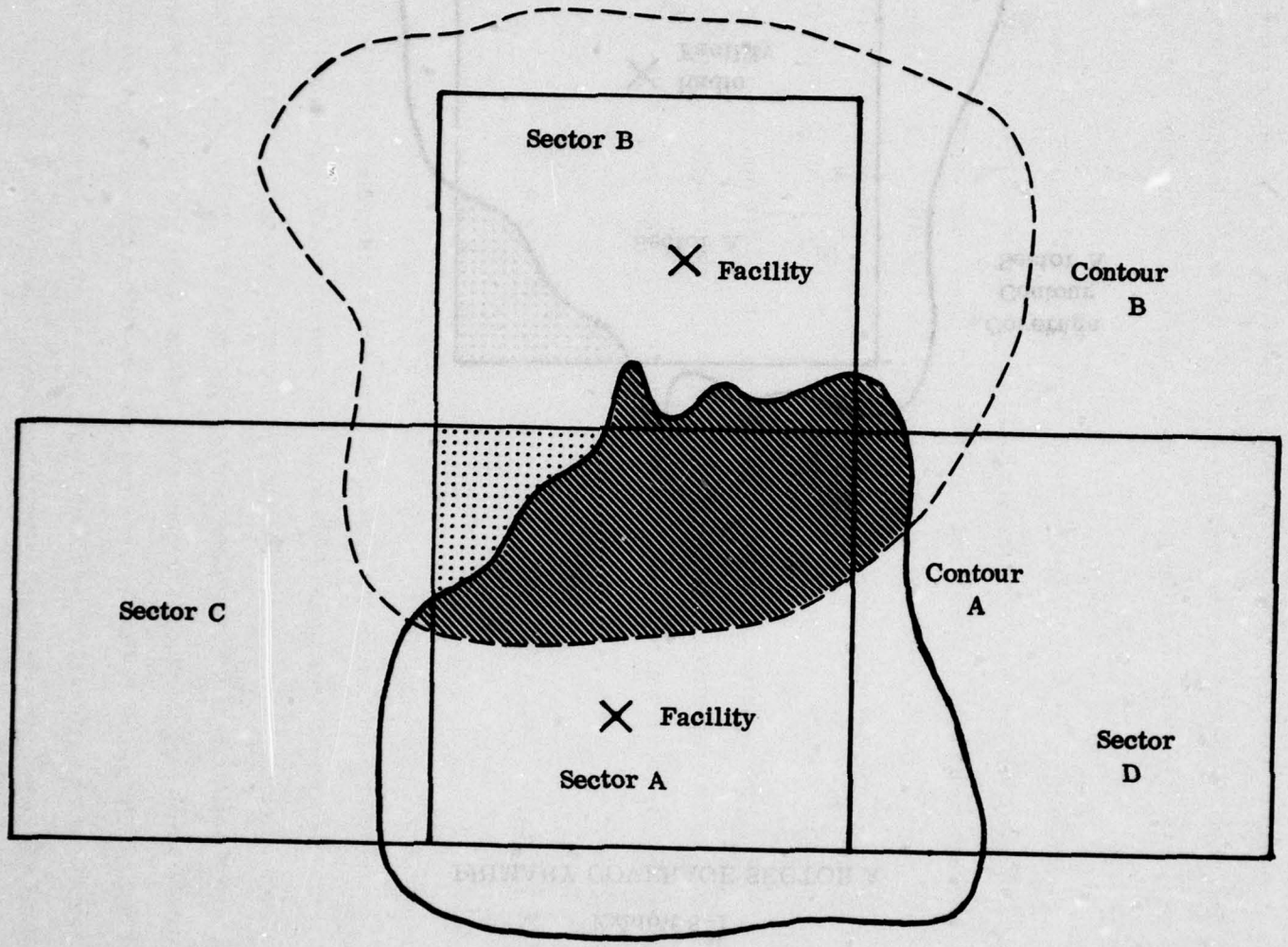


Exhibit 8-2

REDUNDANT + GAP-FILLER COVERAGE SECTOR A



primary radio facility, with 1 to 5 percent of the operations employed at a second radio facility for routine gap filler coverage (i.e., predetermined). The incidence of use of the redundant or secondary coverage should be extremely low (e.g., less than .01 percent) as it is necessary only upon catastrophic failure of the primary radio facility and/or its remoting telephone circuits. Thus, under normal operations, the controller would use the primary radio facility with intermittent use of adjacent facilities to provide gap filler coverage for specified areas when aircraft enter these areas.

When there is a radio failure, the controller would switch to backup radio equipment located at the primary radio facility. The same process would take place for telephone line failures. Failure of both primary and backup radios would cause the controller to switch to an adjacent facility to obtain redundant coverage. Based upon operating experience, it may be effective, in terms of increased service availability, to employ the redundant coverage more frequently.

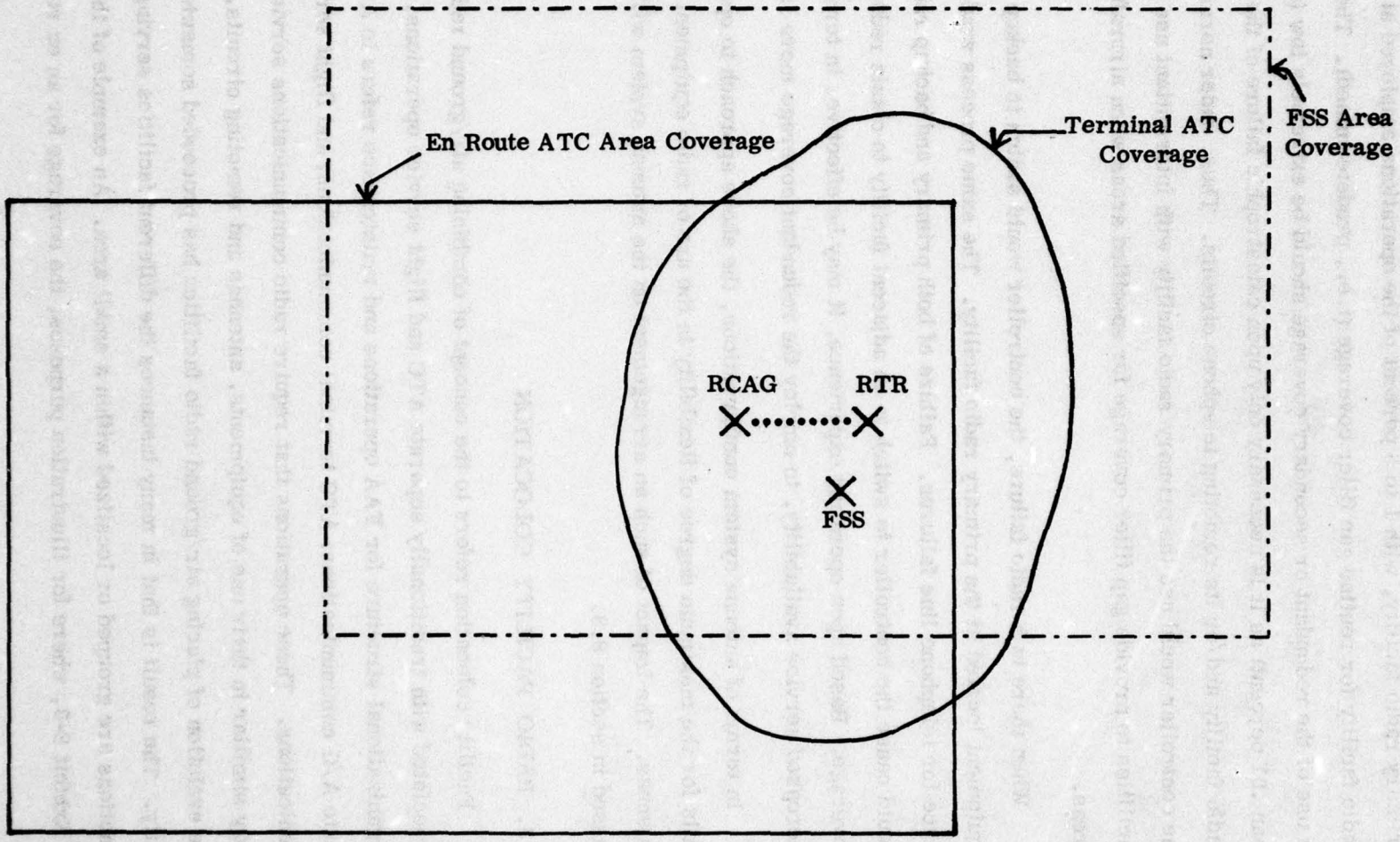
In terms of antenna system configurations, the above approach to operations calls for the maximum degree of flexibility in the use of radio equipment and antennas. The impact of such an arrangement on the antenna system will be discussed in section 8.3.

8.3. RADIO FACILITY COLOCATION

Facility colocation refers to the concept of combining air/ground radio functions associated with traditionally separate ATC and flight service operations. The organizational structure for FAA operations and maintenance refers to ATC en route A/G communications; ATC terminal communications; and flight service communications. These operations that require radio communications services are very similiar in their use of equipments, antennas and remoting circuits. However, the evolution of placing air/ground radio facilities has proceeded somewhat independently. The result is that in many instances the different facilities serving the three functions are grouped or localized within a small area. An example of this is shown in Exhibit 8-3, where for illustration purposes, the coverage for an en route ATC

Exhibit 8-3

RCAG; RTR; FSS COVERAGE AREAS



sector, a terminal ATC sector, and a flight service area are depicted. If the three facilities are located within a localized area of a few miles, indicating approximately concident radio coverage capabilities, then it is useful to consider combining the facilities within a single complex. The combination process involves operating a radio facility with more than the usual number of radio channels. For example, if the RCAG has a 4 channel assignment, the RTR has a 6 channel assignment, and the FSS has a 2 channel assignment, then the single combined facility would support a total of 12 radio channels.

It is evident that a number of combinations are possible among the three facilities by combining en route-terminal; en route-FSS; FSS-terminal; FSS-en route-terminal, etc. Some of these combinations exist in the current FAA configuration.

Additionally, the three facilities may be employed in a wide number of further combinations to provide redundant and/or gap filler coverage, as discussed in the previous section.

As examined in the Phase I effort of this project, the concept is one in which a Universal Radio Facility with modular building blocks (depending upon the application) is used throughout the National Airspace System to support all the functions requiring air/ground radio communications. This is the concept that would logically be employed if an entirely new air/ground radio system was designed to support current and future operations. However, the present system has evolved over a long period with many modifications and improvements being added to the existing structure.

As discussed in the Phase I Report, the benefit is considerable and includes savings in real estate (building lease costs), manintenance costs, radio equipment costs, and telephone leased circuit costs.

The key element in colocation is the ability to concentrate an increased number of radio channels within a bounded area (i.e., within the space available for a single radio facility).

Thus, two limits exist to the degree of colocation possible:

(1) The combination of facilities is limited by the requirements for line of sight radio coverage as modified by terrain, and other obstacles.

(2) The combination of facilities is limited by the capability to operate an increased number of radio channels without degradation of performance due to antenna interactions, pattern distortion, and RFI.

Section 8.4 shows that a considerable expansion of radio channels is feasible by employing multicoupler technology.

8.4 ANTENNA SYSTEMS

In order to concentrate an increased number of radio channels within a limited space without the degradation caused by a multiple number of antennas operating in proximity to one another, it is necessary to consider the use of single antenna configurations. From the results of the experimentation discussed in Chapter 7. it appears that the use of a single antenna, center mounted on the tower platform, and isolated from the platform by a half wavelength nonmetallic mount, provides a regular pattern in the horizontal plane.

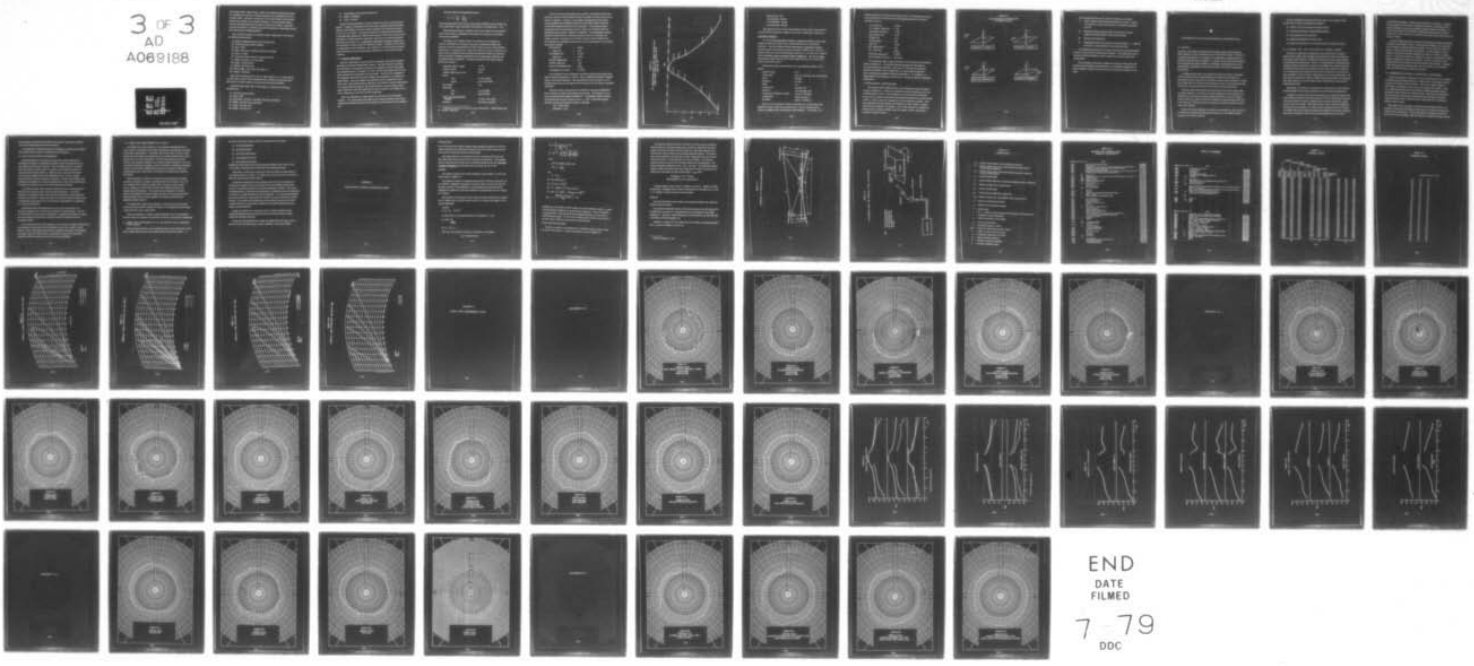
The antenna system for supporting multichannel operations indicated by the analysis and experimentation comprises a single antenna configuration connected to a specified number of radio equipments through a transmitter combiner-receiver multicoupler network. The method by which this configuration achieves the objectives of Universal Radio Facility application is discussed in section 8.5. This section presents the characteristics of the antennas utilized in such a configuration as well as the interfacing combiner-multicoupler network.

8.4.1 Antennas

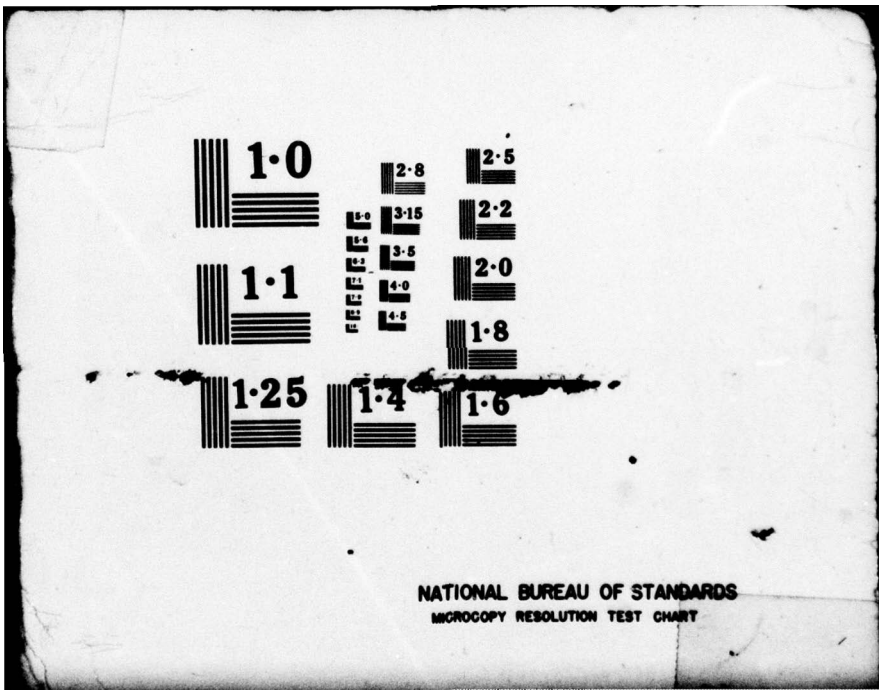
To attain the maximum degree of system flexibility in antenna utilization, it is necessary to use a general purpose antenna, i.e., broadband and omnidirectional. Since paired frequency operations (one VHF and one UHF) are inherent to FAA air traffic control, it is natural to integrate the antenna system for a single radio channel. This can be accomplished by employing a stacked antenna which combines a VHF and

AD-A069 188 VERVE RESEARCH CORP ROCKVILLE MD F/G 17/2.1
ADVANCED COMMUNICATIONS SYSTEMS SUPPORT. AIR/GROUND RADIO ANTEN--ETC(U)
JAN 78 J HANSEN, A WEBSTER DOT-FA75WAI-570
UNCLASSIFIED VS-44 FAA-RD-78-11 NL

3 OF 3
AD
A069188



END
DATE FILMED
7 79
DDC


1·0
1·1
1·25
2·8
3·15
3·5
4·0
4·5
2·5
2·2
2·0
1·8
1·4
1·6
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

UHF antenna within a single radome. While it is evident that added signal margin is a desirable asset, the use of multisite operations will compensate for the lack of signal margin. Therefore, the provision of an omnidirectional stacked antenna with gain over a dipole is not considered essential. It was shown that collinear arrays of two dipoles provide an average of 2 db gain over a dipole. Employing more than two dipoles in a collinear array and the stacking two independent antennas will lead to excessive handling problems.

Thus, the general purpose of a standard antenna configuration is one that has the following characteristics:

(1) Stacked configuration (lower UHF and upper VHF)
(2) Vertically polarized dipole antennas
(3) Gain: +2 dbi
(4) Band: VHF (118 to 136 MHz); UHF (225 to 400 MHz)
(5) Power: 50 watts
(6) Cross band antenna isolation: greater than 40 db
(7) VSWR: less than 2 to 1 across band
(8) Length: less than 8 feet
(9) Weight: less than 15 lbs
(10) Wind Loading: 65 Kt with 2 inch radial ice
(11) Radome: fiberglass

There may be requirements for use of a single antenna (i.e., a vertical dipole) at either VHF or UHF for RCO installations where a difficult coverage gap exists that can only be filled by adding a remote facility with limited capability.

A general purpose single VHF or UHF antenna is one that has the following characteristics:

(1) Vertically polarized dipole
(2) Gain: +2 dbi
(3) Broad band: VHF (118 to 136 MHz); UHF (225 to 400 MHz)
(4) VSWR: less than 2 to 1 across band
(5) Length: less than 4 feet
(6) Weight: less than 5 lbs

(7) Wind loading: 65 Kt with 2 inch radial ice

(8) Radome: fiberglass

(9) Power: 50 watts

Finally, for special situations, it may be necessary to emply a directional gain antenna. A number of alternatives exist in this area, including stacked folded dipole antennas, yagi antennas, and corner reflector antennas--all of which provide gains of 3 to 15 db over a dipole. The present project did not evaluate the characteristics of directional gain antennas but reference may be made to the NAFEC evaluation effort described in a NAFEC publication (publication information is currently unavailable). Directional gain antennas (*i.e.*, folded dipole configurations and yagi antennas) have been employed in various regions for additional coverage. In addition to their special use (supporting one radio frequency), their construction, involving multiple elements, raises questions about their environmental suitability over a wide range of weather conditions.

8.4.2 Receiver Multicouplers

Receiver multicouplers are active devices comprising a wide band RF amplifier followed by an isolation and distribution network. The power division loss through the multicoupler is compensated by the gain of the amplifier so that the total signal gain through the device is nominally 0 to +2 db. Receiver multicouplers that are currently available will accommodate up to 32 channels. Such devices are adaptable to FAA utilization as they allow the use of multiple radio frequencies for reception by a single antenna. Thus, the complete communication receiver configuration can be served with a single stacked antenna connected to VHF and UHF receiver multicouplers. For current RCAG tower layouts, this concept would use one tower platform with a single stacked (VHF and UHF) antenna that is center mounted to accommodate all receiver requirements of both VHF and UHF frequencies.

There is no degradation of signal margin due to the gain of the multicoupler amplifier. The overall system noise figure may be improved relative to the current configuration by adding several db of power gain over that required for loss compensation.

The noise figure for concatenated devices is:

$$F_t = F_1 + \frac{F_2}{G_1} + \frac{F_3}{G_1 G_2} + \ldots$$

so that the noise figure of the receiver (F_2) would be divided by the excess gain (G_1) of the multicoupler. F_1 (the multicoupler noise figure) is nominally about + 8 db.

Since the device employs an amplifier and a power supply, and is connected to N (up to 32) receivers, consideration must be given to the impact on air/ground radio system availability.

No statistics are available on Mean Time Between Failure (MTBF) for receiver multicouplers, but analysis of the series components included in the amplifier result in an estimated MTBF of over 50,000 hours (for a 20 port device)*. Specifications for available devices range from a MTBF of 100,000 to 250,000 hours, which would be consistent with 20 receivers with individual MTBFs of 5,000 hours. The use of parallel redundant configurations for the multicouplers would provide the required service availability. Nominal characteristics for a state of the art device are as follows:

Signal gain (input to output)	+ 3 db
Number of ports	up to 32
Isolation (output port to port)	30 db
VSWR	
Input	2:1 (at 50 ohms)
Output	1.5:1 (at 50 ohms)
Noise figure	8 db
Band width	
VHF	(118-135 MHz)
UHF	(225-400 MHz)
Third order intermodulation rejection	-75 db at 0 dbm output
Reliability	250,000 hrs. (MTBF)

*"Reliability Estimate for the VHF Receiver Multicoupler", Resdel Engineering Co., Arcadia, California.

The use of receiver multicouplers has no effect on minimization of RFI since the devices pass the received signals through the amplifier and perform distribution without any filtering. Therefore, the selectivity characteristics of the receiver front end (usually in the preselector filter) serve to provide isolation among the various radio frequencies passed by the multicoupler. The preselector filters employed in the current solid state receivers result in the composite selectivity performance shown earlier in Exhibits 5-24 and 5-25. For a transmitter-receiver separation of 80 feet which is realized on separate towers for transmitter and receiver antennas, the space loss at 120 MHz is 42 db as shown in Exhibit 5-26. The calculation for transmitter power into the receiver multicoupler is for an 80 foot separation at 120 MHz:

Tx Power Out	=	47 dbm
Cable loss	=	-2 db
Tx Combiner loss	=	-2.5 db
Space loss	=	-42 db
Receiver antenna gain	=	0 db
Receiver cable loss	=	-2 db
Receiver multicoupler gain	=	+3 db
Total Signal Into Receiver	=	+1.5 dbm

At a transmitter-receiver frequency separation of 200 kHz the tolerable input signal to avoid desensitization is -20 dbm. Thus, an additional attenuation of approximately 18 db would be desirable. This represents the worst case both in terms of minimum space loss at the low edge of the VHF band and also the minimum separation of 200 kHz.

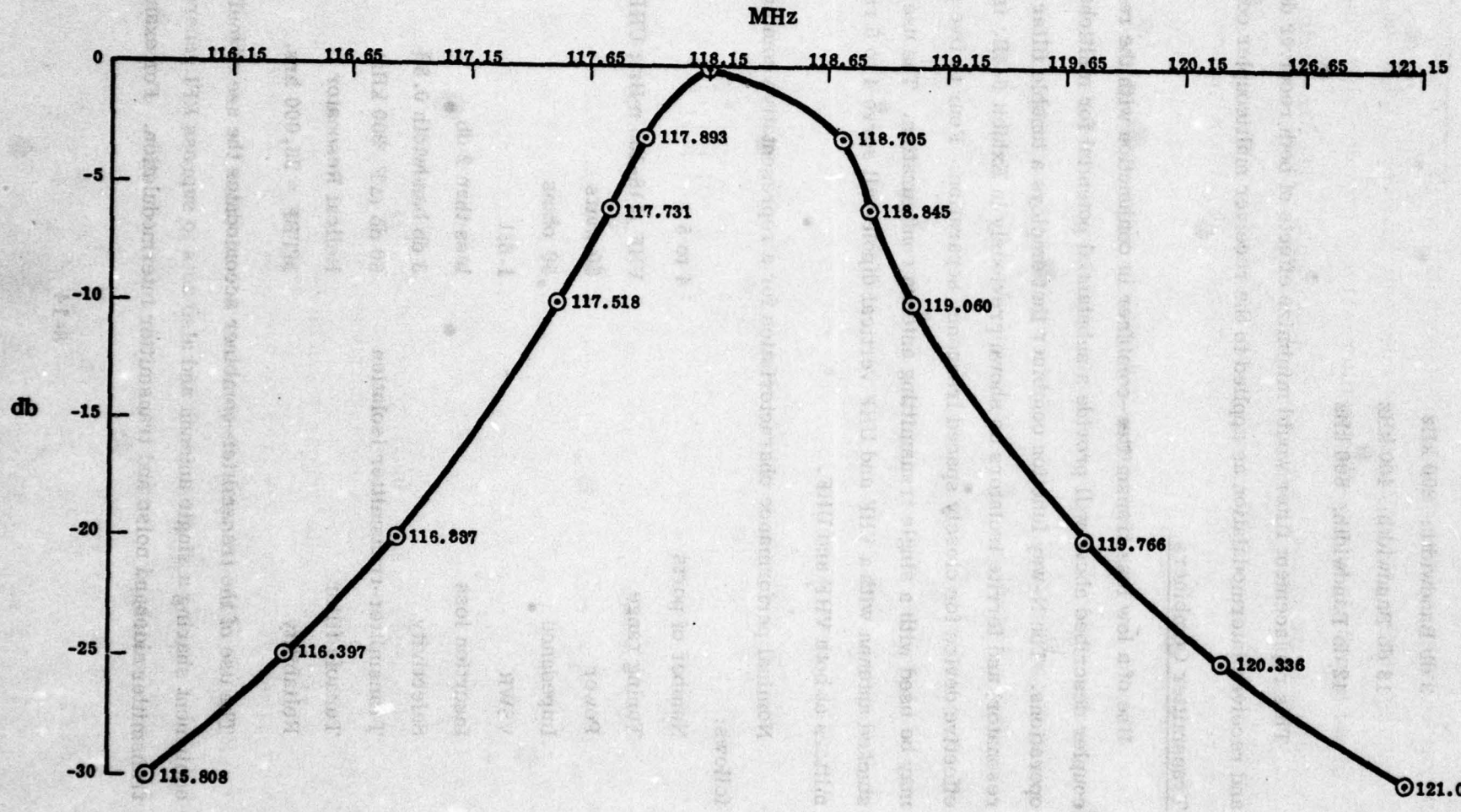
Increased receiver selectivity may be obtained by replacing the preselector filter currently used with a more sharply selective filter. Measurements for the current preselector filter appear in Exhibit 8-4. By employing a helical resonator with approximately the same insertion loss (i.e., 6 db), a 4-pole filter with the following response characteristics should be realizable:

Type: Helical filter

Bandwidth: 0.15%

Exhibit 8-4

RF PRESELECTOR FILTER UNIT FROM AN/GRR-23 RX
SERIAL #21694 USED IN RX SERIAL #21687
August 30, 1977



Insertion loss: 6 db

3 db Bandwidth: 200 kHz

18 db Bandwidth: 400 kHz

42 db Bandwidth: 800 kHz

This replacement filter would minimize effects of both receiver desensitization and receiver intermodulation as applied to the receiver multicoupler configuration.

Transmitter Combiners

Use of a low loss transmitter-combiner in conjunction with the receiver multicoupler described above will provide a substantial potential for multichannel operations. The N-way function combiner that employs a tunable filter (helical) resonator) and ferrite isolators as shown previously in Exhibit 6-4B, is the most effective device for closely spaced frequency separation. Four to five port combiners may be used with a single transmitting antenna configuration. The use of a single stacked antenna with a VHF and UHF vertical dipole will serve 4 to 5 radio transmitters at both VHF and UHF.

Nominal performance characteristics for a representative combiner are as follows:

Number of ports	4 to 5
Tuning range	VHF (118-136 mHz); UHF (225-400 mHz)
Power	50 watts
Impedance	50 ohms
VSWR	1.5:1
Insertion loss	less than 2 db
Selectivity	3 db bandwidth 0.3%
Transmitter-transmitter isolation	60 db (ΔF >800 kHz)
Tunable filter	Helical Resonator
Reliability	MTBF = 25,000 hrs.

The use of the transmitter-combiner accomodates the use of multiple radio equipment sharing a single antenna and also acts to supress RFI generated by transmitter sideband noise and transmitter intermodulation. For example, for a

frequency separation of 300 kHz and 50 watts of power, the transmitter intermodulation interference level at the receiver multicoupler located 80 feet distant is calculated as follows:

Tx A-power out	47 dbm
Tx A isolator-cavity loss	-2 db
T_B isolation at 300 kHz	-60 db
T_B conversion loss	-31 db
T_B cable loss	-2 db
Tx antenna gain	0 db
Space loss	-47 db
Rec. antenna gain	0 db
Rec. cable loss	-2 db
Interfering Signal Level	-97 dbm
Desired Signal Level (3 μV)	-103.4 dbm

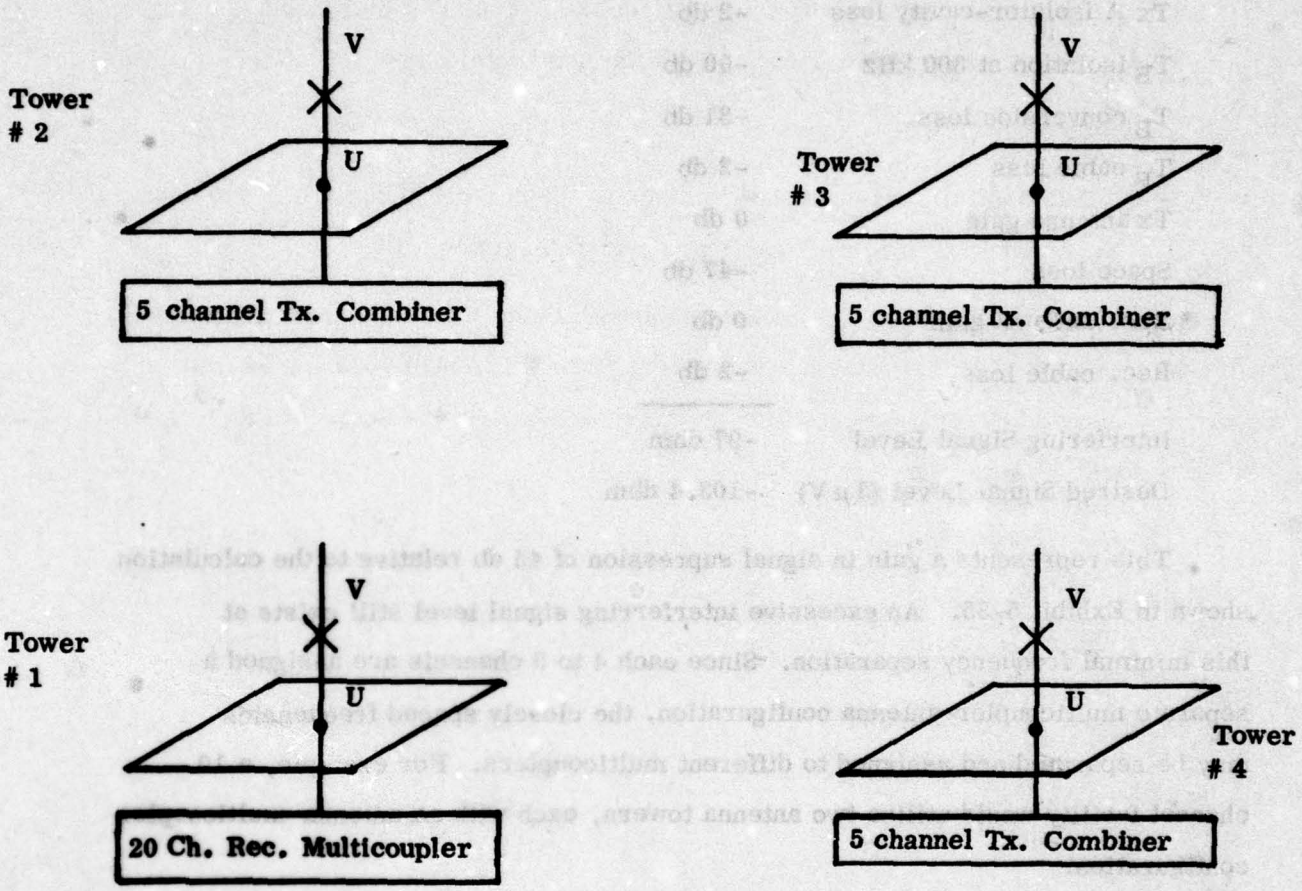
This represents a gain in signal supression of 45 db relative to the calculation shown in Exhibit 5-35. An excessive interferring signal level still exists at this minimal frequency separation. Since each 4 to 5 channels are assigned a separate multicoupler-antenna configuration, the closely spaced frequencies may be separated and assigned to different multicouplers. For example, a 10 channel facility would utilize two antenna towers, each with an antenna-multicoupler configuration.

8.5 MULTICHANNEL CONFIGURATIONS

The antenna system configuration for use in multichannel operations appears as shown in Exhibit 8-5. Tower #1 is reserved for receiver operations and carries a stacked antenna (1 VHF + 1 UHF) connected to a N-port receiver multicoupler. Towers #2, #3, and #4 are reserved for transmitter operations with a stacked antenna (1 VHF + 1 UHF) on each tower connected to a 5 port transmitter combiner. With this configuration the total capacity of the facility is 15 radio channels--roughly 4 times the current capacity of 4 channels. The 15 radio channels are employed for primary sector coverage; redundant cover over adjacent sectors; and gap filler coverage for adjacent sectors.

Exhibit 8-5

MULTICHANNEL CONFIGURATION
A/C RADIO FACILITY



Four principal advantages occur with this arrangement, as follows:

(1) Larger capacity radio facility which permits co-location, response to increased air activity and provision for redundant and gap filler services.

(2) Minimizes antenna proximity effects and results in increased regularity of antenna patterns in the horizontal plane.

(3) Results in RFI supression.

(4) Substantially reduces the elements in the outside plant, i.e., antennas, connectors, mounting hardware and transmission lines.

The configuration described is the result of the analysis and experimentation carried out as part of this present Phase II Program. The configuration was not procured, tested and evaluated as such an effort was beyond the scope of the present effect.

The next chapter will present a program for subsequent efforts which will recommend the development and assessment of a multichannel configuration as well as extension of efforts into the terminal communications and flight services areas.

9

RECOMMENDED ADVANCED R&D PROGRAM FOR AIR/GROUND RADIO

9.1 GENERAL

The Phase I and II efforts associated with the present research and development (R&D) program for radio communications have examined the concept of a universal air ground radio facility and, in particular, the application of antenna systems to achieve the required service availability. It remains for the results of these efforts to be employed in the system definition, development, and procurement of a cost-effective Radio Communication Control System (RCCS), and Radio Communication System (RCS).

As indicated in this report, the scheduled time and level of effort was insufficient to provide the scope of experimentation and amount of data necessary to fully characterize the many factors that influence antenna system operations. Further, the principal effort was directed toward examination of the en route air/ground radio facility with no appreciable analysis of the terminal and FSS environments.

While this initial experimentation was carried out at the NAFEC facility under controlled conditions, it is necessary to verify and apply the results obtained by extending the test environment to include selected field sites in the various regions. By this method, the results to date may be employed to support field operations and, at the same time, valuable data may be collected and assessed to validate and augment current findings.

Finally, the eventual objective in carrying out an R&D effort on radio systems is to integrate the analytical and experimented results into a cost-effective system design for both the RCCS and RCS.

Verve has identified the following areas that require a more extensive effort to support the air/ground communications program:

(1) analysis, test, and evaluation of antenna systems,

(2) combiner/multicoupler configuration development,

(3) field applications and assessment,

(4) design and development of a RCCS, and

(5) design and development of an air/ground Radio Communication System.

9.2. ANALYSIS, TEST, AND EVALUATION OF ANTENNA SYSTEMS

This task is a continuation and expansion of the current Phase II Program. Because of the complex radio propagation environment that exists in the vicinity of multi-antenna radio facilities, theoretical analysis provides only an approximation to antenna pattern characteristics. However, an accumulation of experimental data collected by antenna range tests as well as various flight tests will allow an empirical formulation that describes expected performance under operational conditions. It is recommended that an additional series of tests be performed to more fully examine the effects of various antenna configurations in the en route environment. The tests should be conducted to evaluate 1) antenna-tower perturbations to the horizontal and vertical patterns, 2) aircraft antenna system characteristics, and 3) vertical lobing characteristics.

Additionally, the approach to experimentation utilized for the en route facilities should be applied to the terminal and flight service radio facility configurations.

Facilities for terminal area radio communications are potentially exposed to far greater distortion effects in both the horizontal and vertical antenna patterns because of the larger number of antennas employed and the numerous obstructions usually present at airport terminals. Since facility siting is often restricted to designated locations that are not optimum, the antenna system configuration must be designed to provide surface and low altitude coverage under difficult environmental conditions. The practice of using ATC tower roofs as antenna pedestals has led to intense

concentrations of antennas mounted in close proximity to one another. It appears that the application of transmitter-combiners and receiver multicouplers offers a practical solution to terminal communication facility configuration problems. To make an assessment and recommend a standardized design consistent with that employed for en route operations, sufficient test data describing terminal operations must be collected.

The current FSS Improvement Program will substantially modify the supporting air/ground communications system. The introduction of FSS-Hubs in some areas and the retention of manned Flight Service Stations in other areas will result in a mixture of manned and unmanned radio facilities. In many instances it may be possible to combine the FSS radio capability with either an en route or terminal facility. It may also be necessary to implement a number of Remote Control Outlets (RCOs) to augment the present radio coverage. The RCO can be placed at any existing facility that is located to provide the required radio coverage. Colocation of RCO antennas and radio channels with other FAA facilities such as RCAGS, RTRS, and VORTACS should be analyzed and tested.

9.3 COMBINER/MULTICOUPLER CONFIGURATION DEVELOPMENT

The use of transmitter-combiners and receiver-multicouplers for the reduction of multiple antenna arrangements places a larger degree of importance on the performance and reliability of these elements. The loss of a single combiner or multicoupler can potentially result in the loss of multiple radio channels. Therefore, sufficient protection should be provided by employing redundant elements controlled by fault detection and switching circuits. The design and development of the multicouplers and ancillary monitoring and switching devices should be integrated with the remote monitoring system configuration and the centralized technical control concept.

With regard to the performance of combiner and multicoupler devices, it is necessary to review the availability and state of the art for helical resonators and receiver active multicouplers. Several representative configurations should be procured for test and evaluation within the context of an operational antenna system.

Upon completion of experimental validation and evaluation, appropriate specifications can be developed and issued for procurement.

The application of combiner/multicoupler configurations should include employment in the en route, terminal, and flight service environments.

9.4 FIELD APPLICATIONS AND ASSESSMENTS

In the development of a universal air/ground radio facility, the degree of realizable universality or standardization achieved is directly related to the variable conditions encountered in the field. Each FAA Region presents a variety of radio communication problems that are a function of the particular locality and associated environmental conditions. Sufficient visits to several of the regions have provided a sampling of the system degradations due to terrain, multiple antenna operations and radio frequency interference. However, the techniques and configurations developed as a result of experimentation at the NAFEC facility should be employed in the field as part of the overall improvement program.

A principal advantage of field operations assessment is that recommended configurations are evaluated in their normal working environment. A secondary advantage is that additional data, which more fully describe the various phenomena that occur, are collected. Finally, the impact on the entire air/ground system is one of performance improvement with proven techniques being adopted for standardized use in all field installations.

Careful planning for field applications can assure that any particular site operation in support of ATC is not adversely affected by experimentation. This can be accomplished by the use of dual configurations or sequenced substitutions or both so that the current level of operation is maintained until the modification has been thoroughly verified.

Verve recommends that a Field Application and Assessment Program be initiated and and conducted as a joint activity with participation of ARD, AAF, NAFEC, and the Regions. Since a considerable effort has been expended in the analysis of the Oakland area (ZOA), this area, which contains a wide range of terrain and environmental conditions, should be selected as the site of the initial undertaking.

9.5. DESIGN AND DEVELOPMENT OF AN RCCS

The original and current concept of a voice frequency signaling system for radio control is complicated by the addition of flexible and cost-effective automation to the remote radio facilities. The present radio control system is used to switch between main and standby radio equipments and to provide a keying closure, that is, push to talk, to the remote transmitter. With the incorporation of more cost-effective radio equipment redundancy as provided by tunable transceivers, the move to automated maintenance techniques, and the substitution of combiner/multicoupler devices, the radio control configuration becomes more complex by adding more signaling options and a return path to accommodate site performance monitoring information.

Further flexibility is required to respond to the requirements for providing secondary and gap filler coverage as described earlier in this report. Also, the use of multiple radio facilities to provide radio coverage for larger airspace sectors, requires the use of facility selection radio channel activation at the controller specialist position. The incorporation and integration of all these features with substantial automation support comprises the next generation RCCS. Future operations must be DABS compatible and interface with the data link capability provided by DABS.

It is evident that a single system approach is warranted for the RCCS design to provide assurance that the multiple new features are compatible and flow through a single processor at the remote facility.

Work is in progress on a number of RCCS subsystems and it is recommended that these efforts be combined and coordinated to achieve a cost-effective configuration.

9.6 DESIGN AND DEVELOPMENT OF AN AIR/GROUND RADIO COMMUNICATIONS SYSTEM

The final design decisions for all component elements of the RCS should be based upon an engineering analysis for the complete Radio Communication System. As

described in the Phase I Report, the RCS is comprised of five elements:

(1) the terminal position,

(2) the Telco facilities,

(3) the remote radio facility,

(4) the propagation path, and

(5) the aircraft radio system.

Modification of the design of any of these subsystems affects all the others so that a total systems viewpoint must be maintained in the engineering design.

Additionally, consideration of appropriate interface design and engineering for such adjacent systems as NADIN, TCS, DABS, NAS, and the VCS must be carried out within the context of the total RCS system.

Of particular significance to the development of the RCS is the introduction of automation in a number of areas that showed result in more effective performance as well as a substantial reduction in the system maintenance workload. The various switching functions, control logic and fault detection configurations should be engineered on the basis of a single integrated processing subsystem. It is evident that distributed processing will likely be implemented with satellite processors located at the remote facilities. The introduction of digital logic and processing systems must be accommodated within the AF maintenance organization which implies additional training, logistics and documentation.

Finally, the ultimate user of the RCS is the Air Traffic Controller and any system implementation must be measured by the cost and performance benefits realized by controller operations.

The above recommendations for a number of related tasks will result in an improved RCS that will exhibit faster response, flexibility, and gorwth potential.

APPENDIX A

CALCULATION OF VERTICAL PROPAGATION LOBES

INTRODUCTION

One of the aids that was used to compare actual propagation conditions to some consistent reference in the evaluation and analysis of the FAA antenna system environment was the vertical lobe structure of ideal dipoles.

This lobing structure was computed in the 118 to 136 MHz and the 200 to 400 MHz radio bands which are used in FAA air/ground communication. The technique used to develop the lobe structures was a technique developed in the book Ultra High Frequency Propagation by Henry Reed and Carl Russell (pp. 127 to 149).

METHOD

The method is based on the two path propagation model (Exhibit A-1) and on the system shown in Exhibit A-2.

The technique assumes an essentially smooth earth; an effective earth factor (K) of 4/3 (NOTE: although the assumption of 4/3 earth radius is not strictly valid over the entire airspace, it was employed as a crude approximation that was deemed sufficient) and significant air/ground propagation at grazing angles (θ) from 1 degree to 10 degrees.

The procedure (in the sequence used by Reed and Russell) applied to the computation of a single point on the lobe structure contour is as follows (see Exhibit A-3 for symbol explanation):

Compute

(1) $h_1 = h_1' - (1/2)\, d_1^2$

(a small value of d_1 is generally chosen, for example $d_1 = .5$ mi)

(2) $\tan \theta = \dfrac{h_1'}{5280 d_1}$

(3) $d_2 = d_T - d_1$

Note: d_T is the range that is chosen as a reference, for example,

$d_T = 50$ statue miles.

$$(4)\quad D = \left[1 + \frac{2d_1^2\, d_2}{h_1' d_t}\right]^{-1/2}$$

$$(5)\quad R_e^{J\phi} = \frac{\underline{n}^2 \sin\theta - \sqrt{\underline{n}^2 - \cos^2\theta}}{\underline{n}^2 \sin\theta - \sqrt{\underline{n}^2 - \cos^2\theta}}$$

where

$\underline{n}^2$ is a complex number with

$$\underline{n}^2 = \epsilon_r - \frac{j\sigma}{\omega \epsilon_o}$$

and

$$\omega = 2\pi f_o$$

$$(6)\quad h_2' = 5280\, d_2 \tan\theta$$

$$(7)\quad h_2 = h_2' + (1/2) d_2^2$$

$$(8)\quad \phi = (1.385 \times 10^{-4}\, h_1'\, h_2'\, f_o)/d_T$$

$$(9)\quad g(\phi) = \left[1 + (DR)^2 + 2DR \cos(\phi - \beta)\right]^{1/2}$$

$$(10)\quad d = \frac{.0243\, (P_t R_r / L_{sys})^{1/2}}{V f_o}\, g(\phi)$$

Equation (10) is the result we seek to enable us to plot the distance (range) for a given receiver terminal voltage (V) at a given receiver height (h_2). If these calculations are performed for several distances to the reflection point (d_1) over the range of allowable grazing angles, we can use the resulting points to plot the contour that represents a given voltage (V) at the receiver input terminals.

LOBE COMPUTER PROGRAM

The above procedure was translated into a FORTRAN computer program which was used for the analysis. A copy of the program is shown in Exhibit A-4.

The program computed the values of d based on the users input of transmitter antenna height (h_1); operating frequency (f_o); transmitter output power (not ERP); system loss (Lsys); and desired voltage contour (V). The output range (d) was in nautical miles and the contours were primarily microvolt contours. The system loss used was generally a nominal value of 6 dB. Output power was one of the two values used by FAA, 10 watts (40 dBm) or 50 watts (47 dBm). The operating frequency varied across the 118 to 136 MHz and the 200 to 400 MHz bands. The contours typically examined were 6μV, 12μV, and 48μV. The transmitter antenna height was either the typical RCAG tower height value of 55 feet or the value of the optimum (for solid radio coverage) antenna height, h_{opt}, where

$$\log_{10}(h_{opt}) = 3.38 - \log_{10} f_o$$

(from Exhibit 5-14, for overland links.)

A typical program output is shown in Exhibits A-5 and A-6. Exhibit A-5 shows the input data, debugging values of some of the parameters, and tables of h_2, R and, $\phi - \emptyset$. Exhibit A-6 shows the values of d for the data.

RESULTS

The values generated by the computer were plotted according to the method outlined by Reed and Russell.*

It was discovered that the variation of the lobe structure in the VHF band (118 to 136 MHz) was very small so a representative plot was developed at 126.25 MHz (Exhibit A-7). Similarly, a lobe structure plot was developed for the UHF band (225 to 400 MHz) at 343 MHz (Exhibit A-8).

Examples of contours for 118.5 MHz and for 126.25 MHz at an optimum height of 19 ft. are shown in Exhibits A-9 and A-10.

---

*Reed and Russell, p. 137.

Exhibit A-1

GEOMETRY OF TWO-PATH PROPAGATION

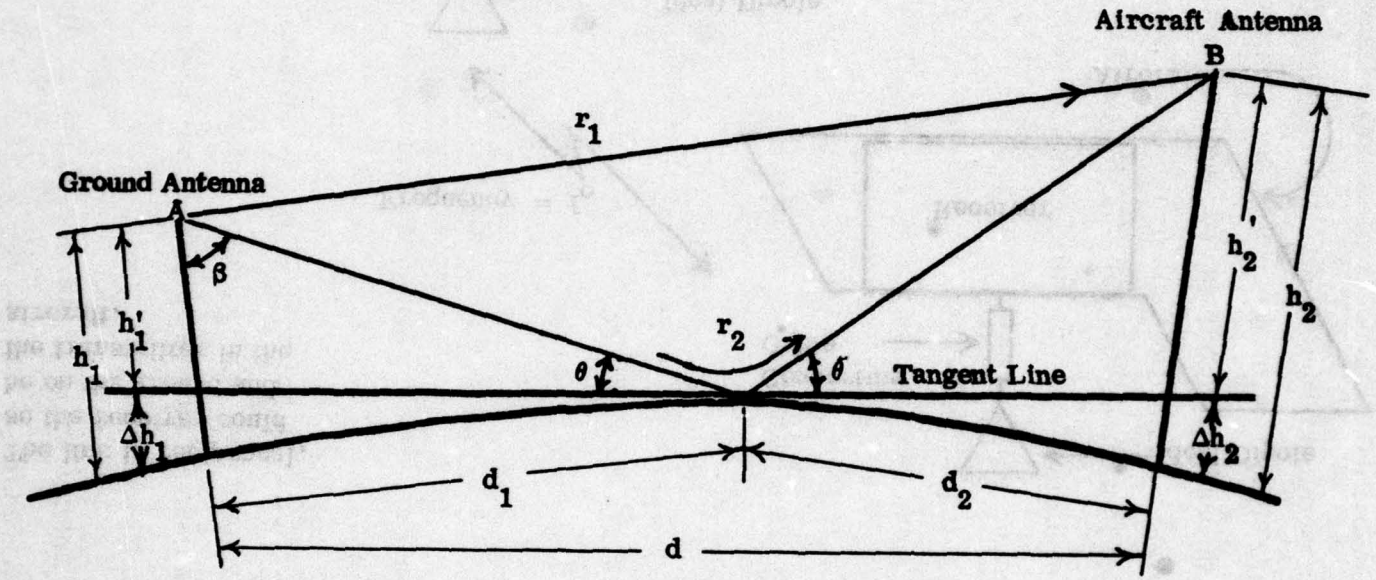


Exhibit A-2

AIR/GROUND LINK FOR VERTICAL LOBE CALCULATION

Note: The link is reciprocal, so the receiver could be on the ground and the transmitter in the aircraft.

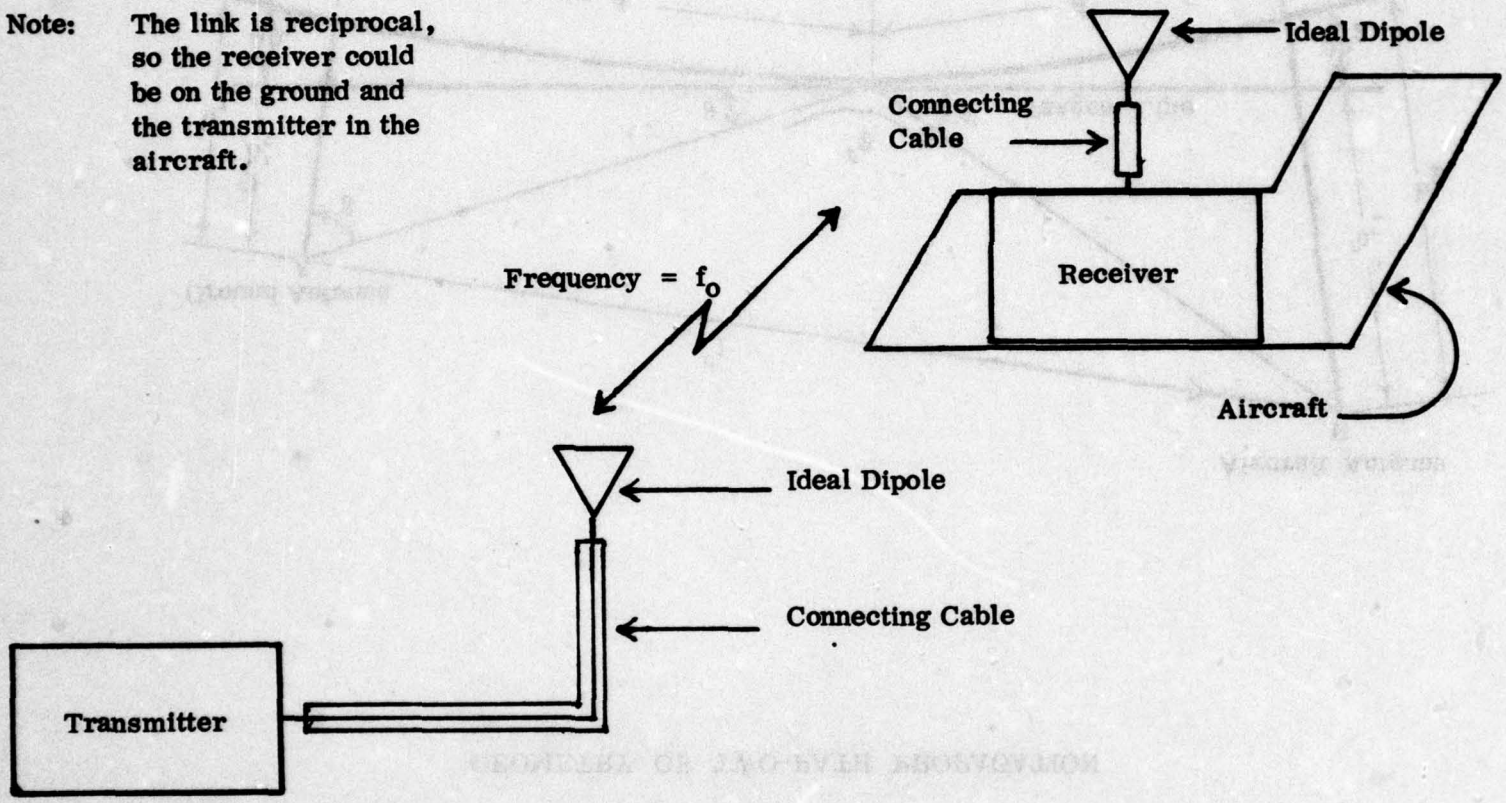


Exhibit A-3

SYMBOLS USED

d_T = distance along surface of the earth between antennas,

d_1 = distance along surface of the earth between the ground antenna and the point of reflection

d_2 = distance along surface of the earth between the point of reflection and the aircraft antenna

h_1 = ground antenna height

h_1' = ground antenna height above tangent line (tangent at point of reflection)

Δh_1 = altitude of tangent line at ground station

h_2 = aircraft antenna height

h_2' = aircraft antenna height above tangent line

Δh_2 = altitude of tangent line at the distance d from ground station

r_1 = direct-ray path between antennas

r_2 = indirect-ray path between antennas

θ = grazing angle

$\beta \doteq 90° - \theta$ = angle of elevation measured with respect to the antenna axis

σ = conductivity of the earth surface

ϵ_r = relative permittivity of the medium

ϵ_o = free space permittivity

f_o = operating frequency (in MHz)

Lsys = system loss (primarily connector losses)

V = voltage at receiver input terminals

P_t = transmitter output power (not ERP)

R_r = antenna radiation resistance

R = reflection coefficient magnitude

ϕ = reflection coefficient phase

Exhibit A-4

PROGRAM FOR VERTICAL LOBE CONTOUR CALCULATION

```
FORTRAN IV G LEVEL  21                    MAIN

0001                  COMPLEX REL,NSQ,N2SQ,RT,RT2                                    00010000
0002                  REAL LAMBDA                                                    00010100
0003                  DIMENSION DI(138),CHI(138),HP(138),TCH(138),D2(138),HP2(138)   00010200
0004                  DIMENSION H2(138),D(138),TH(138),R(138),PHI(138)               00010300
0005                  DIMENSION DH1(138),DH2(138)                                    00010400
0006                  DATA DI(1),DI(2),DI(3),DI(4),DI(5),DI(6)/.1,.12,.15,.16,.18,.2/ 00010500
0007                  COMMON DR(138),GTH(138),DC(138),DIF(138)                       00010600
                C-                                                                   00010700
0008            35    FORMAT(1H1)                                                    00010800
0009            40    FORMAT(3X,F4.2,F6.2,F8.5,F6.0,F7.0,F6.3,F6.0,F6.0,F6.0,F8.3)   00010900
0010           100    FORMAT(5F10.0)                                                 00011000
0011           200    FORMAT(15F5.0)                                                 00011100
0012           300    FORMAT(1X,F10.2,6F10.0)                                        00011200
0013                  DO 90 I=7,76                                                   00011300
0014            90    DI(I)=DI(I-1)+.01                                              00011400
0015                  DI(77)=1.0                                                     00011500
0016                  DO 91 I=78,138                                                 00011600
0017            91    DI(I)=DI(I-1)+.1                                               00011700
                C-                                                                   00011800
0018                  PER=15.0                                                       00011900
0019                  SIG=.01                                                        00012000
0020            12    READ(5,100,END=900)FREQ,HI,PWR,BOSS,CONT                       00012100
0021                  WRITE (6,35)                                                   00012200
0022                  WRITE(6,300)FREQ,HI,PWR,BOSS,CONT                              00012300
                C-                                                                   00012400
0023                  DO 10 L=1,138                                                  00012500
0024                  DHI(L)=.5*DI(L)**2                                             00012600
0025                  HP(L)=HI-DHI(L)                                                00012700
0026                  IF(HP(L).GT.0.)GO TO 14                                        00012800
0027                  N=L-1                                                          00012900
0028                  GO TO 26                                                       00013000
0029            14    TCH(L)=HP(L)/(5280.*DI(L))                                     00013100
0030                  D2(L)=50.-DI(L)                                                00013200
0031                  DH2(L)=.5*D2(L)**2                                             00013300
0032                  HP2(L)=5280.*D2(L)*TCH(L)                                      00013400
0033                  H2(L)=HP2(L)+DH2(L)                                            00013500
0034                  D(L)=1./SQRT(1.+ (4.*DHI(L)*D2(L)/(HP(L)*50.)))                00013600
0035                  TH(L)=(.0001385*HP(L)*HP2(L)*FREQ)/50.                         00013700
0036                  CHI(L)=ATAN(TCH(L))                                            00013800
0037            10    CONTINUE                                                       00013900
0038                  N=138                                                          00014000
                C-                                                                   00014100
0039            26    LAMBDA=300./FREQ                                               00014200
                C-    ****************                                               00014300
0040                  D(1)=1.0                                                       00014400
                C-    ****************                                               00014500
0041                  CON=-60.*LAMBDA*SIG                                            00014600
0042                  NSQ=CMPLX(PER,CON)                                             00014700
0043                  N1=N + 1                                                       00014800
0044                  DO 27 J= N1,138                                                00014900
0045                  H2(J)=0.                                                       00015000
0046                  DR(J)=0.                                                       00015100
0047            27    DIF(J)=0.                                                      00015200
                C-                                                                   00015300
0048                  DO 20 K=1,N                                                    00015400
0049                  N2SQ=CMPLX(((COS(CHI(K)))**2),0.)                              00015500
0050                  RT=(SQRT(NSQ-N2SQ)                                             00015600
0051                  RT2=NSQ*SIN(CHI(K))                                            00015700
```

Exhibit A-4 (Continued)

```
FORTRAN IV G LEVEL  21                    MAIN

0052                RFL=(RT2-RT)/(RT2+RT)                                    00015800
0053                A=REAL(RFL)                                              00015900
0054                B=AIMAG(RFL)                                             00016000
0055                TEST=B/A                                                 00016100
0056                R(K)=SQRT(A**2+B**2)                                     00016200
0057                PHI(K)=-180. + (ATAN(TEST)*57.3)                         00016300
0058          20    CONTINUE                                                 00016400
              C-                                                             00016500
0059                DO 30 K=1,N                                              00016600
              C-    FOLLOWING ANGLE IN DEGREES*********************          00016700
0060                DIF(K)=TH(K)-PHI(K)                                      00016800
0061          30    DR(K)=D(K)*R(K)                                          00016900
              C-                                                             00017000
0062                WRITE(6,40)(DI(I),DHI(I),TCH(I),DH2(I),H2(I),D(I),TH(I),PHI(I),  00017100
                   &DIF(I),K(I),I=1,5)                                       00017200
0063                WRITE (6,45)(H2(I),H2(I+46),H2(I+92),DR(I),DR(I+46),DR(I+92),  00017300
                   &DIF(I),DIF(I+46),DIF(I+92),I=1,46)                       00017400
0064          45    FORMAT (4X,3F10.0,6X,3F10.3,4X,3F10.0)                   00017500
0065                CALL CONTR (N,CONT,PWR,FREQ,BOSS)                        00017600
              C-                                                             00017700
              C-                                                             00017800
              C-                                                             00017900
0066                GO TO 12                                                 00018000
0067          900   STOP                                                     00018100
0068                END                                                      00018200
```

```
FORTRAN IV G LEVEL  21                    CONTR

0001                SUBROUTINE CONTR (N,CONT,PWR,FREQ,BOSS)                  00018300
0002                COMMON DR(138),GTH(138),DC(138),DIF(138)                 00018400
0003                WRITE (6,5)                                              00018500
0004          5     FORMAT (1H1,20X,'CONTOUR RESULTS FOR DATA',//)           00018600
0005                TOP = SQRT((PWR*50.)/(10.**(BOSS/10.)))                  00018700
0006                BOT = CONT * 1.E-06 * FREQ                               00018800
0007                CONST=(.0243 * TOP)/BOT                                  00018900
0008                DO 10 I = 1,N                                            00019000
0009                DIF(I)=DIF(I) * .01745                                   00019100
0010                VAR = 2. * DR(I) * COS (DIF(I))                          00019200
0011                PAR = 1. + DR(I) * DR(I)                                 00019300
0012                GTH(I) = SQRT(VAR + PAR)                                 00019400
              C-    CONTOUR IN NAUTICAL MILES*********************          00019500
0013                DC(I) = CONST * GTH(I) * .869                            00019600
0014          10    CONTINUE                                                 00019700
0015                WRITE (6,20) (DC(K),DC(K+46),DC(K+92),K=1,46)            00019800
0016          20    FORMAT (4X,3F10.0)                                       00019900
0017                RETURN                                                   00020000
0018                END                                                      00020100
```

Exhibit A-5

PROGRAM OUTPUT

frequency

antenna height

output power

system loss

contour values

Data

118.15		55.		10.	6.	48.			
0.10	0.00	0.10416	1245.	28688.	0.0	494.	-177.	671.	0.413
0.17	0.01	0.08674	1246.	24103.	1.000	411.	-178.	589.	0.485
0.15	0.01	0.06943	1243.	19517.	1.000	329.	-178.	507.	0.565
0.16	0.01	0.06509	1242.	18371.	1.000	308.	-178.	487.	0.587
0.18	0.02	0.05785	1241.	16459.	0.999	274.	-179.	453.	0.624

Diagnostic Aid

28688.	5658.	2064.	0.0	0.866	0.868	671.	259.	196.
24103.	5584.	2018.	0.485	0.868	0.863	589.	258.	195.
19517.	5513.	1975.	0.565	0.870	0.856	507.	257.	194.
18371.	5444.	1934.	0.586	0.871	0.850	487.	255.	194.
16459.	5377.	1896.	0.623	0.873	0.844	453.	254.	193.
14930.	5313.	1859.	0.654	0.874	0.837	425.	253.	192.
14275.	5250.	1825.	0.668	0.876	0.830	413.	252.	192.
13679.	5189.	1792.	0.681	0.877	0.823	403.	251.	191.
13134.	5129.	1760.	0.692	0.879	0.816	393.	250.	191.
12635.	5072.	1730.	0.703	0.880	0.809	384.	249.	190.
12176.	5015.	1702.	0.713	0.881	0.801	376.	248.	190.
11752.	4961.	1674.	0.722	0.883	0.794	368.	247.	189.
11360.	4908.	1648.	0.731	0.884	0.786	361.	246.	189.
10996.	4856.	1623.	0.739	0.885	0.778	355.	245.	189.
10656.	4806.	1599.	0.747	0.886	0.770	349.	244.	188.
10339.	4757.	1575.	0.754	0.887	0.762	343.	243.	188.
10043.	4709.	1552.	0.761	0.888	0.754	338.	242.	188.
9765.	4663.	1531.	0.768	0.889	0.746	333.	241.	187.
9504.	4617.	1509.	0.774	0.890	0.738	328.	241.	187.
9258.	4573.	1489.	0.780	0.891	0.730	324.	240.	187.
9026.	4530.	1469.	0.785	0.892	0.722	319.	239.	186.
8807.	4488.	1450.	0.790	0.893	0.713	316.	238.	186.
8600.	4447.	1431.	0.795	0.894	0.705	312.	238.	186.
8403.	4407.	1413.	0.800	0.894	0.696	308.	237.	186.
8217.	4367.	1395.	0.804	0.895	0.688	305.	236.	185.
8040.	4329.	1378.	0.809	0.896	0.679	302.	236.	185.
7872.	4291.	1361.	0.813	0.897	0.671	299.	235.	185.
7711.	4255.	1344.	0.817	0.897	0.662	296.	234.	185.
7558.	4219.	1328.	0.820	0.898	0.654	293.	234.	184.
7412.	4184.	1313.	0.824	0.899	0.645	291.	233.	184.
7273.	3871.	1297.	0.827	0.904	0.636	288.	227.	184.
7139.	3614.	1282.	0.831	0.908	0.628	286.	223.	184.
7011.	3398.	1268.	0.834	0.910	0.619	283.	219.	184.
6888.	3215.	1253.	0.837	0.911	0.610	281.	216.	183.
6771.	3056.	1239.	0.840	0.911	0.602	279.	213.	183.
6658.	2918.	1226.	0.842	0.911	0.593	277.	211.	183.
6549.	2796.	1212.	0.845	0.909	0.584	275.	208.	183.
6445.	2688.	1199.	0.847	0.907	0.575	273.	207.	183.
6344.	2591.	1186.	0.850	0.904	0.566	272.	205.	183.
6247.	2503.	1173.	0.852	0.901	0.557	270.	203.	182.
6154.	2424.	1160.	0.854	0.898	0.548	268.	202.	182.
6064.	2351.	1148.	0.857	0.894	0.539	267.	201.	182.
5977.	2285.	1136.	0.859	0.889	0.530	265.	200.	182.
5893.	2223.	1124.	0.861	0.884	0.521	263.	199.	182.
5812.	2167.	1112.	0.863	0.879	0.512	262.	198.	182.
5734.	2114.	1100.	0.865	0.874	0.503	261.	197.	182.

h_2 R $\alpha - \phi$

Exhibit A-6

PROGRAM OUTPUT

CONTOUR RESULTS FOR DATA

42.	50.	12.
32.	49.	12.
25.	49.	11.
33.	48.	11.
48.	47.	11.
59.	47.	11.
63.	46.	11.
65.	46.	11.
68.	45.	10.
70.	44.	10.
71.	44.	10.
72.	43.	11.
72.	43.	11.
73.	42.	11.
73.	42.	11.
72.	41.	11.
72.	41.	11.
72.	40.	12.
71.	40.	12.
71.	40.	12.
70.	39.	12.
69.	39.	13.
68.	38.	13.
68.	38.	13.
67.	37.	13.
66.	37.	14.
65.	37.	14.
64.	36.	14.
64.	36.	15.
63.	36.	15.
62.	32.	15.
61.	29.	16.
60.	27.	16.
59.	25.	16.
59.	23.	17.
58.	21.	17.
57.	20.	17.
56.	19.	18.
55.	18.	18.
55.	17.	19.
54.	16.	19.
53.	15.	19.
53.	14.	20.
52.	13.	20.
51.	13.	20.
50.	12.	21.

Exhibit A-7
VERTICAL LOBING STRUCTURE FOR VHF BAND

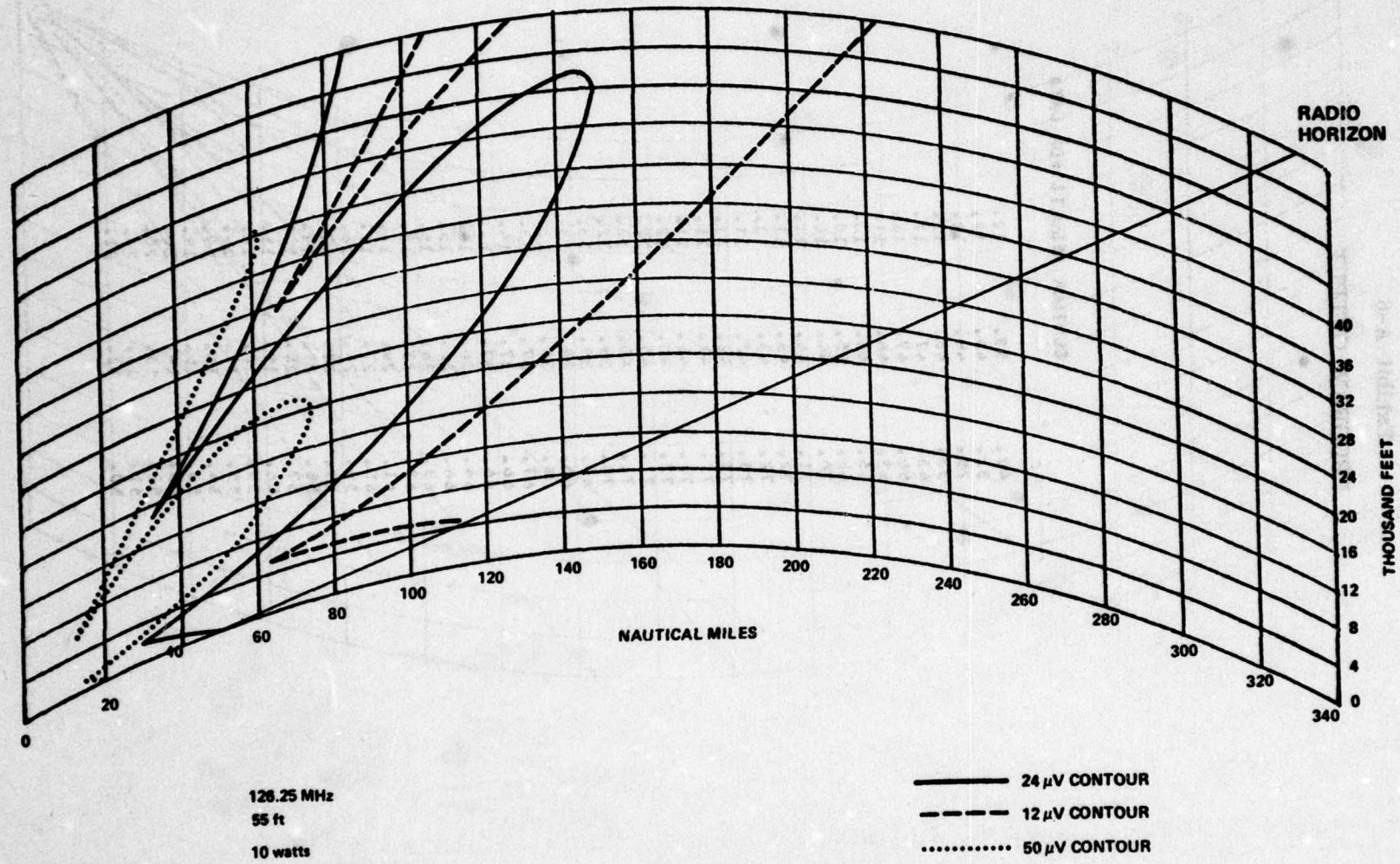


Exhibit A-8

VERTICAL LOBING STRUCTURE FOR UHF BAND

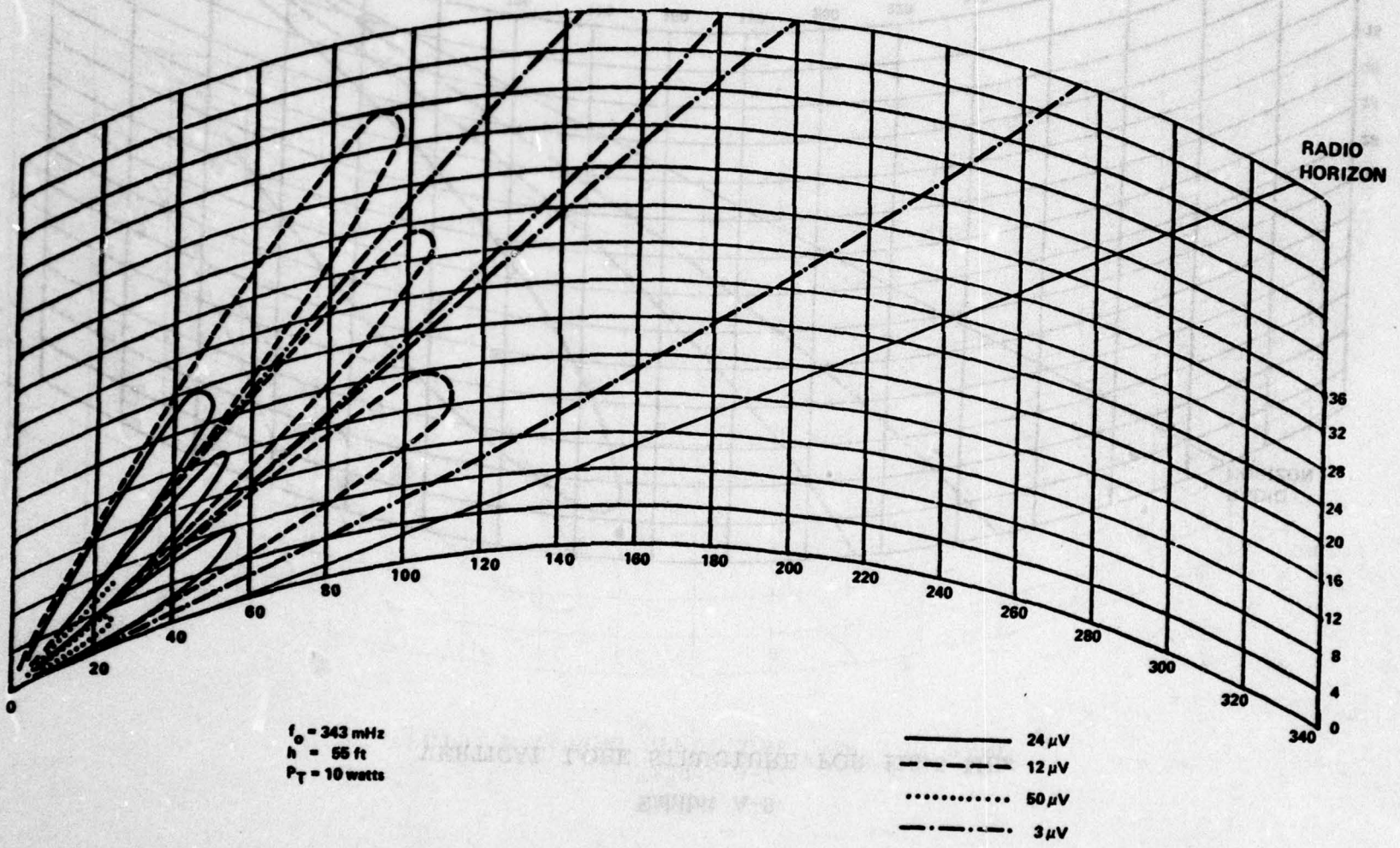


Exhibit A-9

VERTICAL LOBE STRUCTURE FOR 118.5 MHz

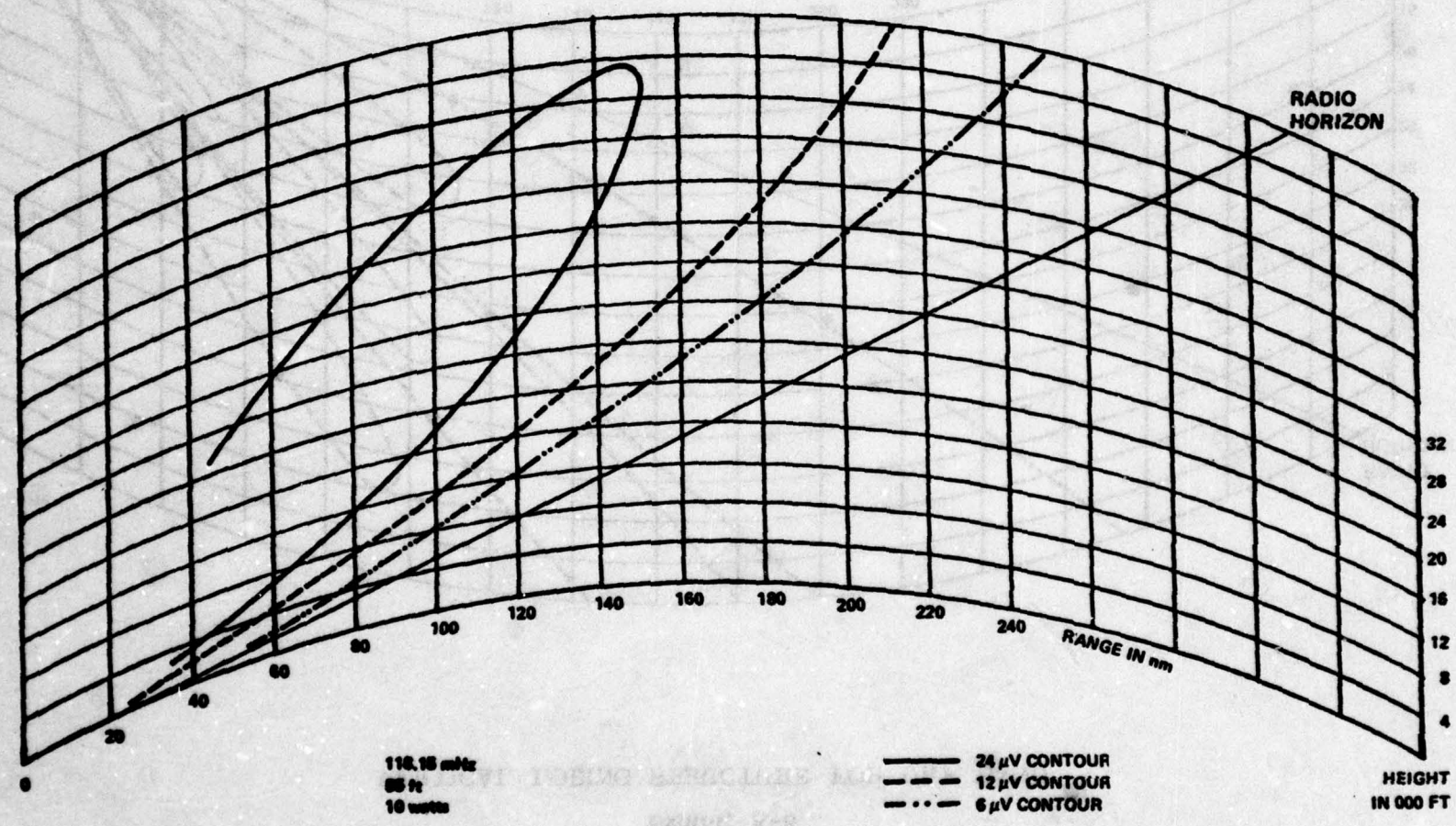
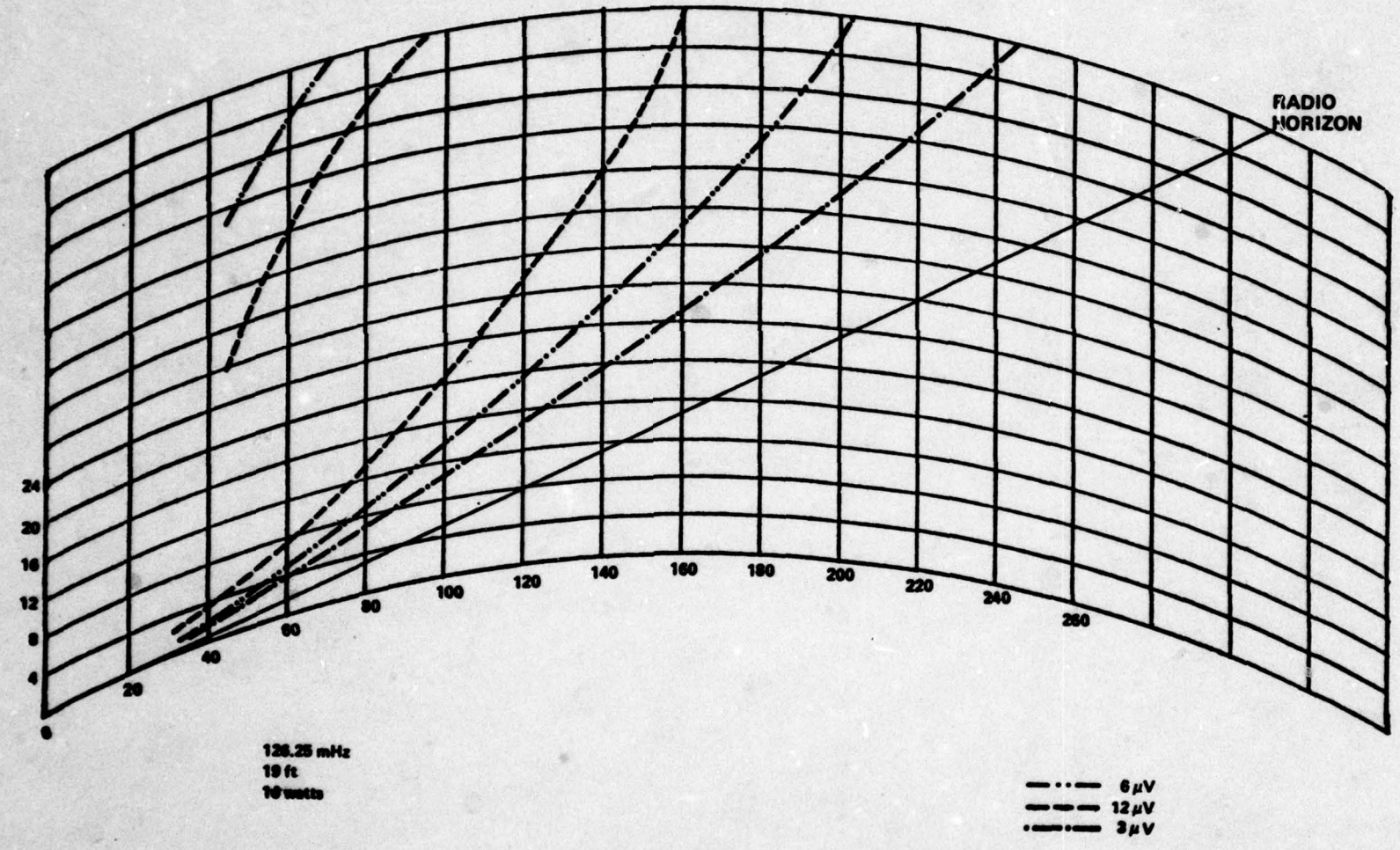


Exhibit A-10

VERTICAL LOBE STRUCTURE FOR 126.25 MHz



APPENDIX B

FLIGHT TESTS EXPERIMENTAL PLOTS

EXPERIMENT NO. 1

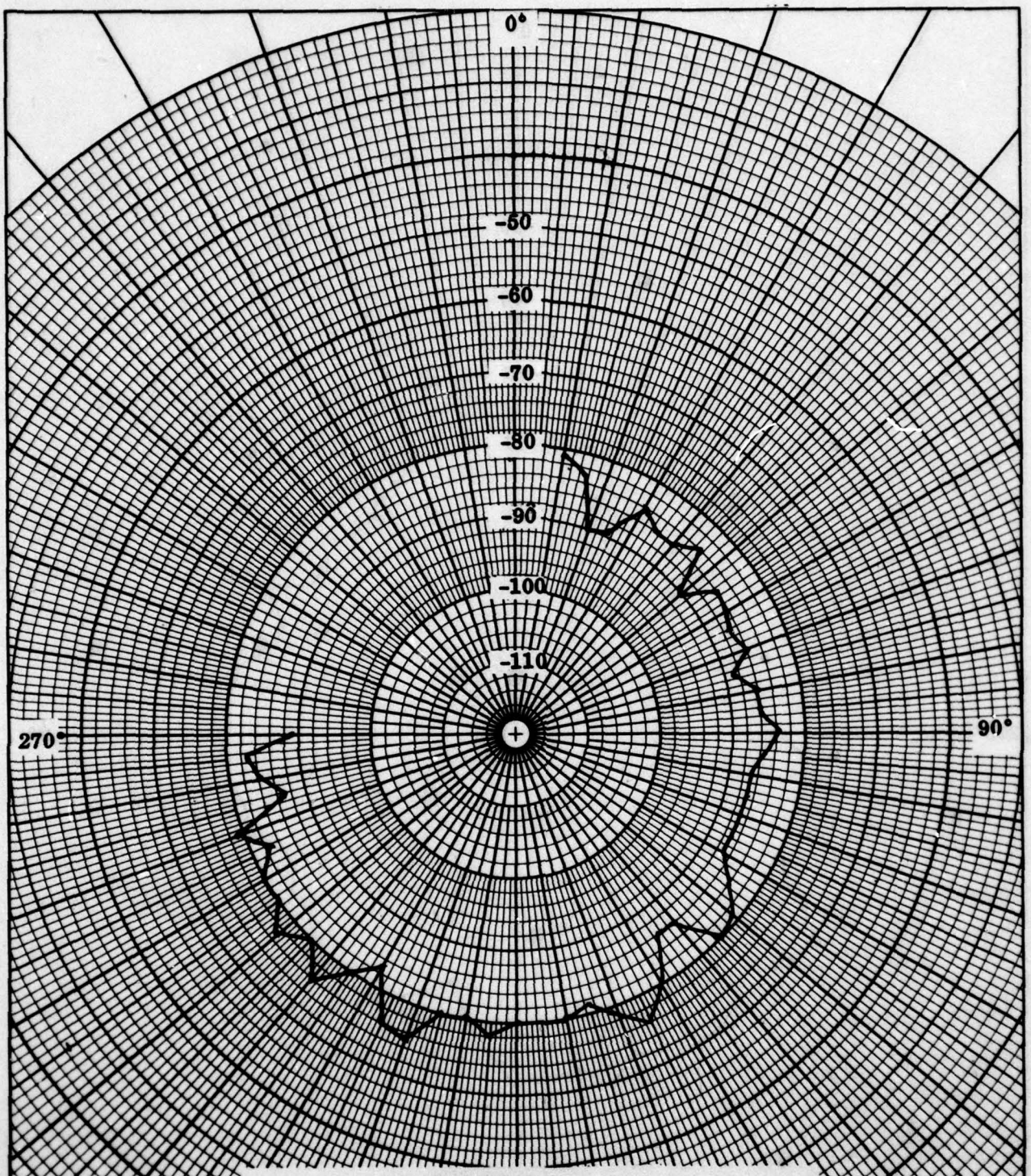


Exhibit B-1

ORBITAL PLOT:
TACO SINGLE V ON 35' PORTABLE TOWER
AT 26.25 MHz
(ORBIT-40 NM)

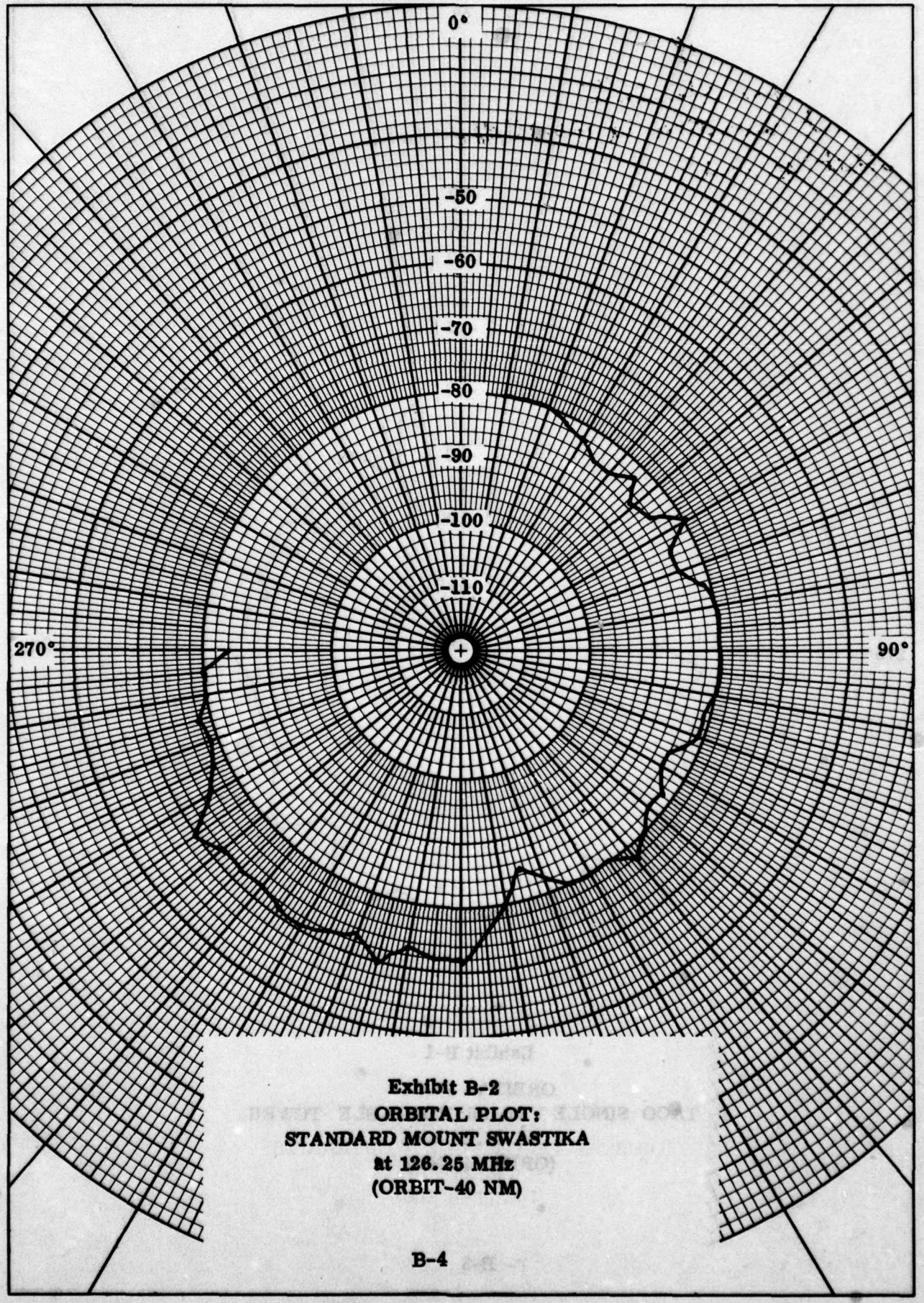


Exhibit B-2
ORBITAL PLOT:
STANDARD MOUNT SWASTIKA
at 126.25 MHz
(ORBIT-40 NM)

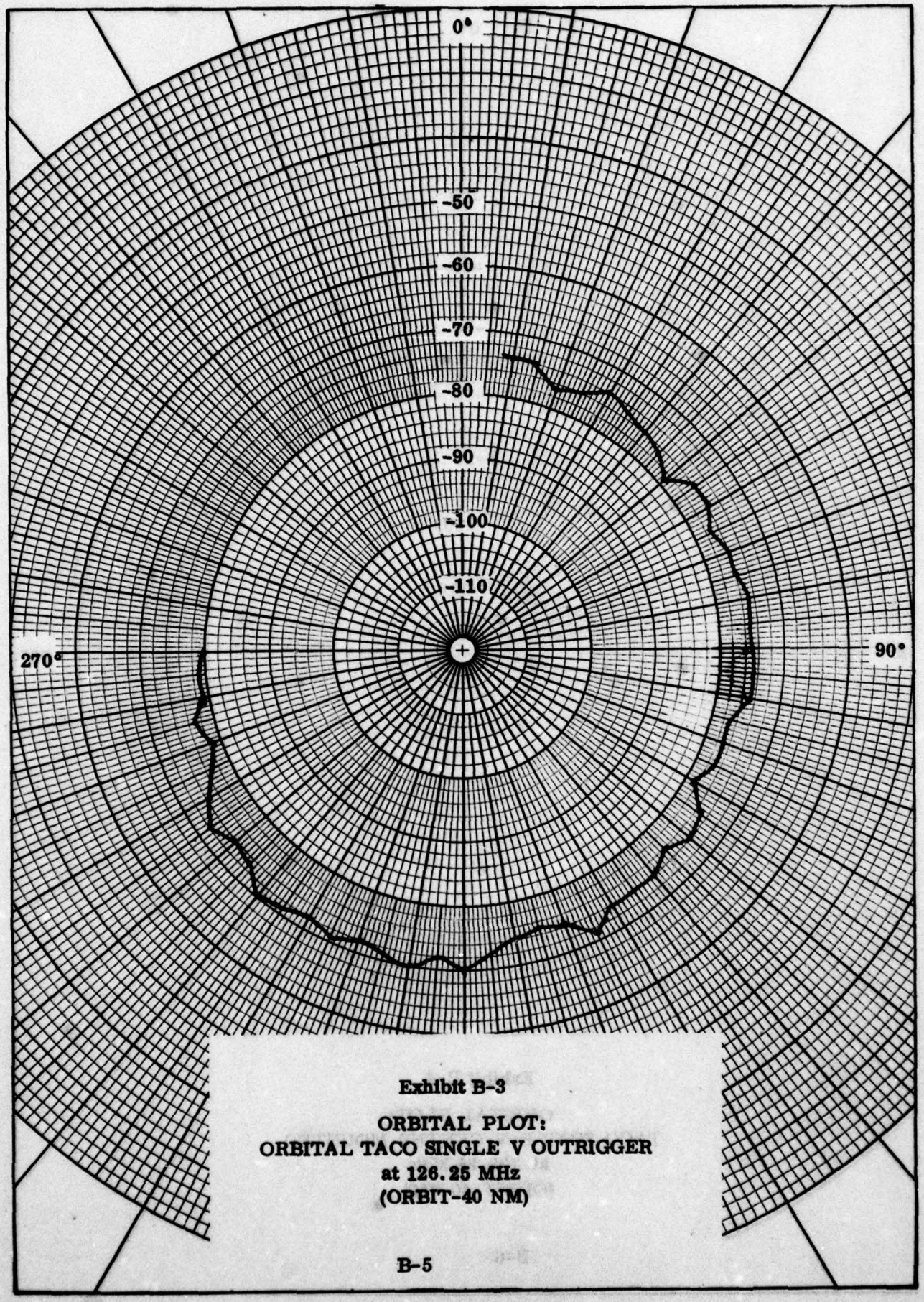


Exhibit B-3

ORBITAL PLOT:
ORBITAL TACO SINGLE V OUTRIGGER
at 126.25 MHz
(ORBIT-40 NM)

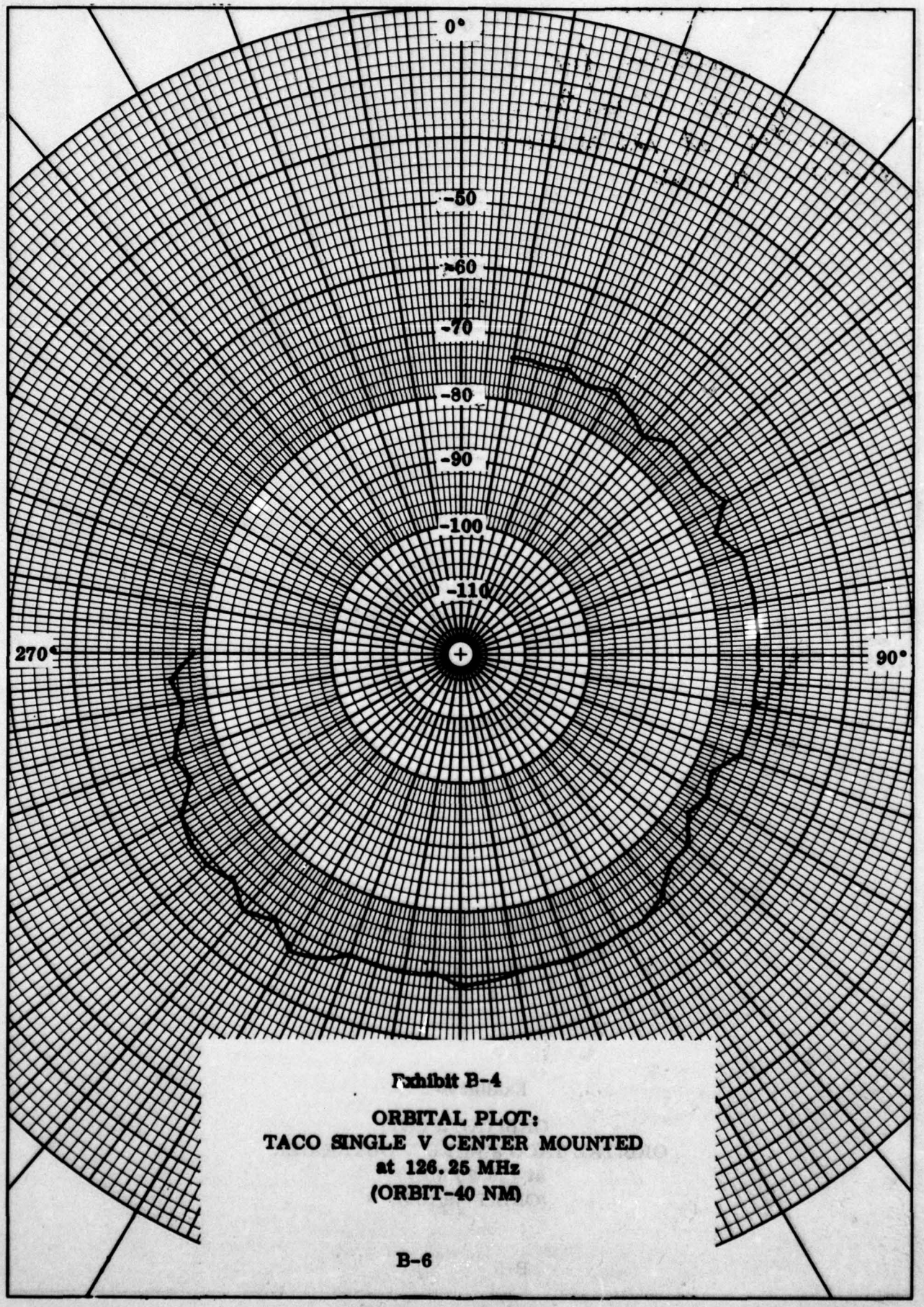


Exhibit B-4

ORBITAL PLOT:
TACO SINGLE V CENTER MOUNTED
at 126.25 MHz
(ORBIT-40 NM)

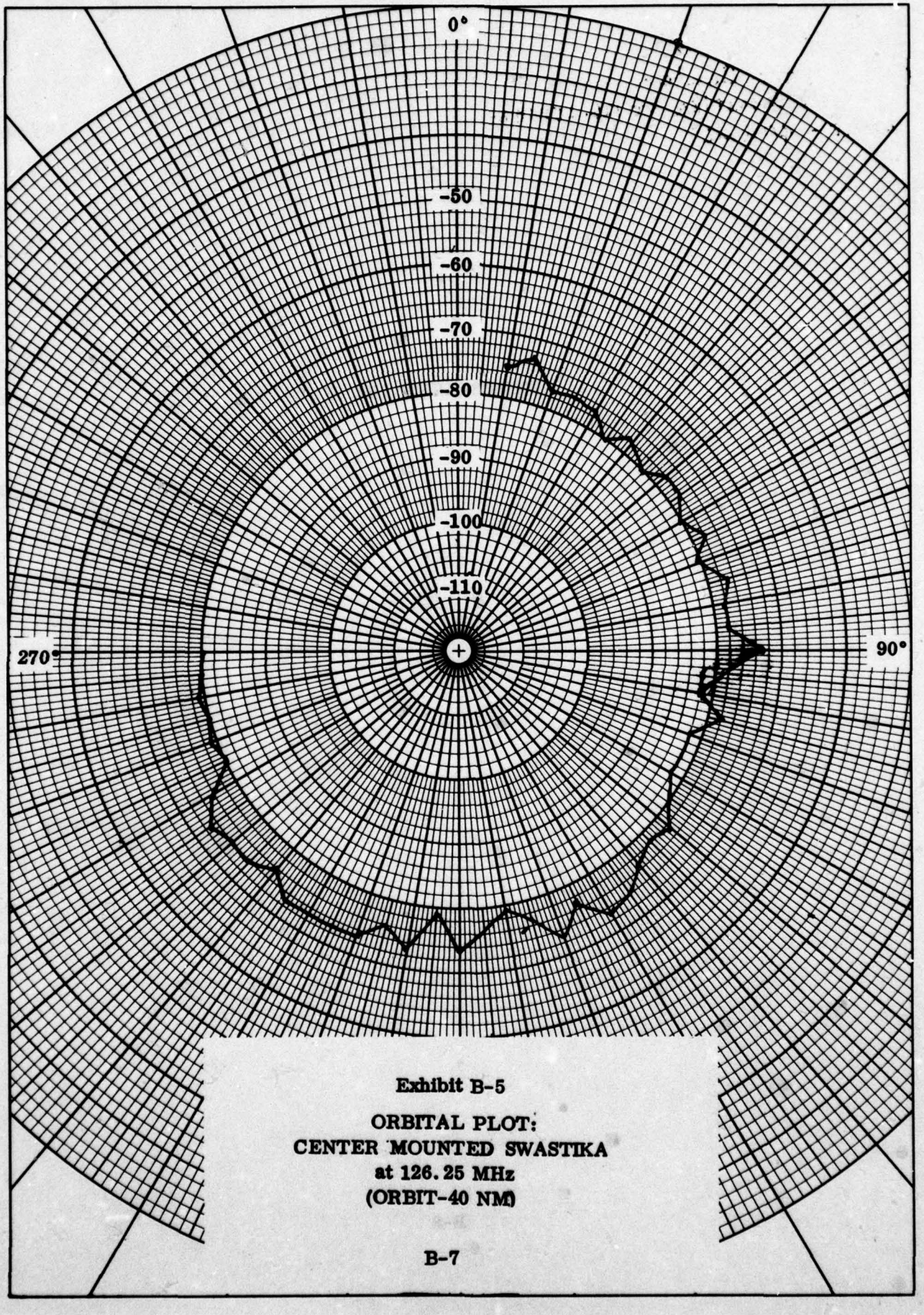
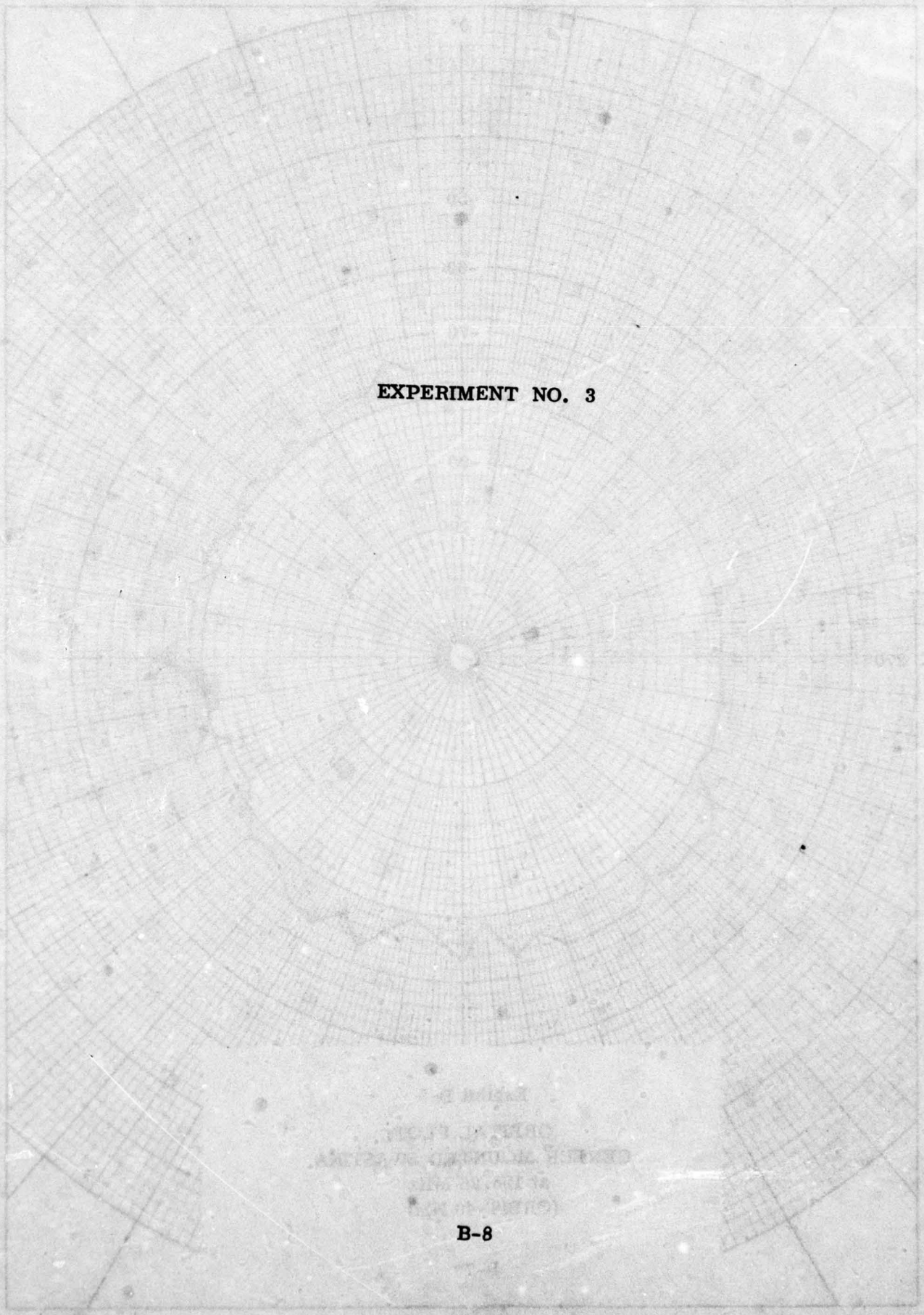


Exhibit B-5

ORBITAL PLOT:
CENTER MOUNTED SWASTIKA
at 126.25 MHz
(ORBIT-40 NM)



EXPERIMENT NO. 3

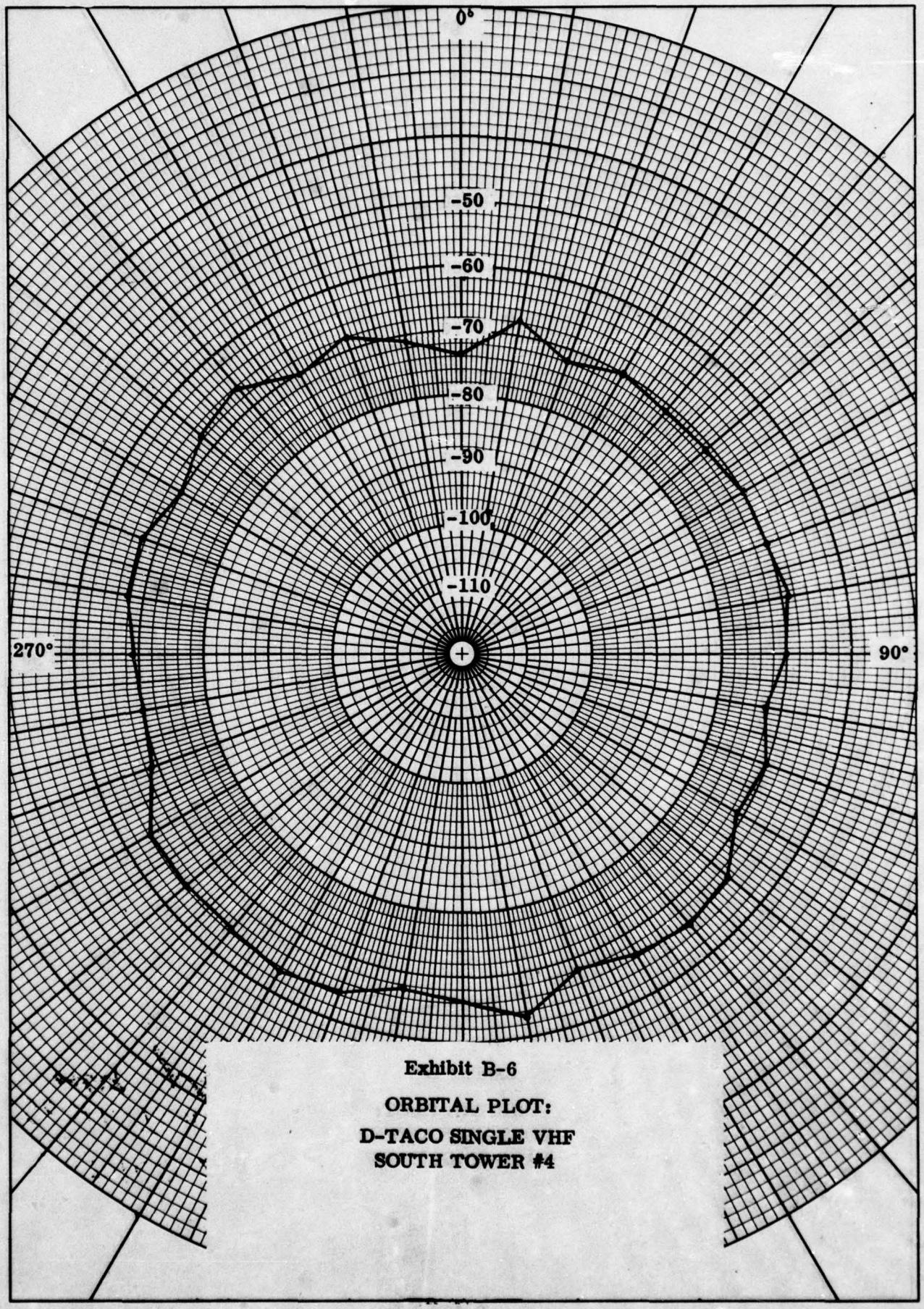


Exhibit B-6

ORBITAL PLOT:

D-TACO SINGLE VHF

SOUTH TOWER #4

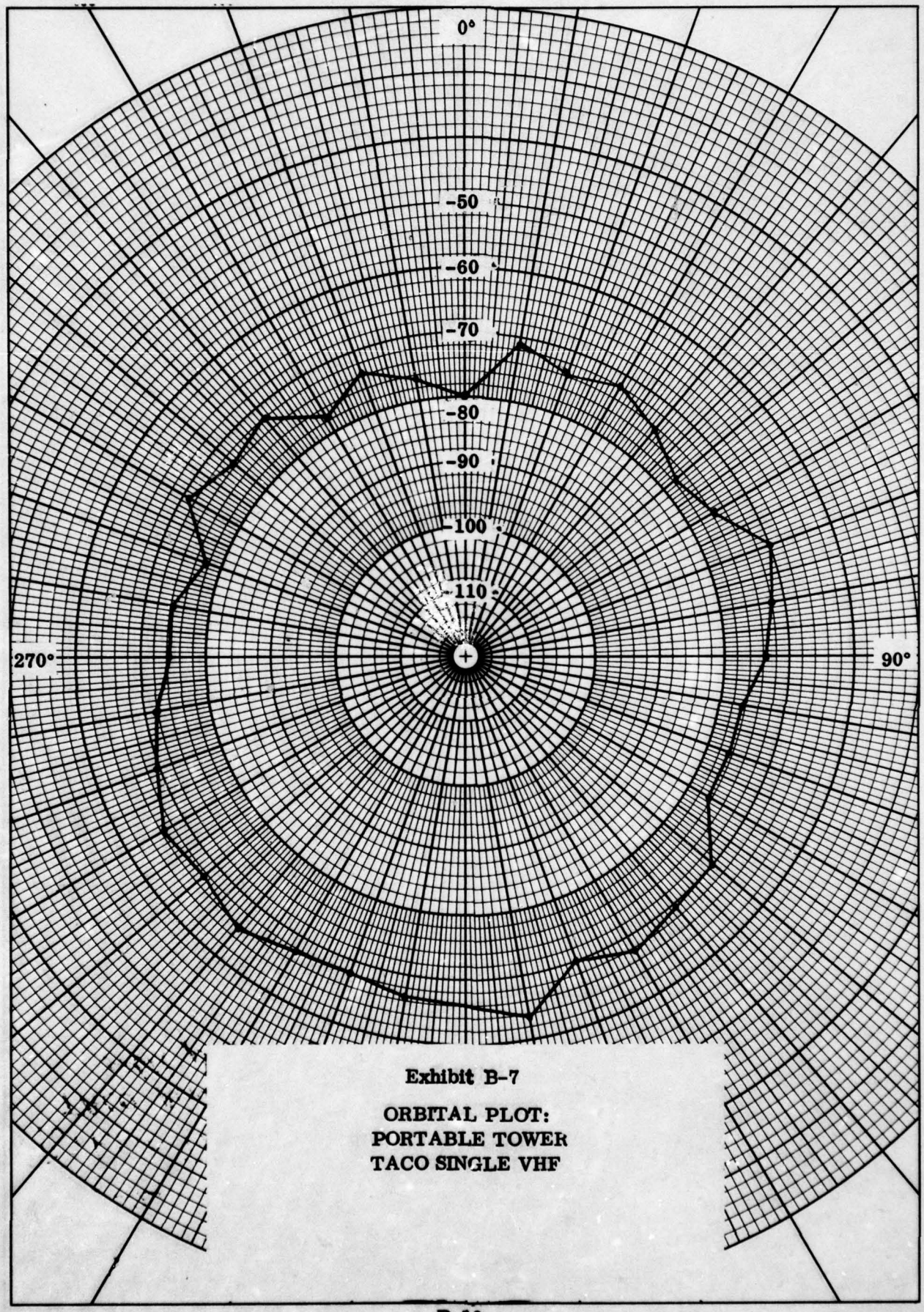


Exhibit B-7

ORBITAL PLOT:
PORTABLE TOWER
TACO SINGLE VHF

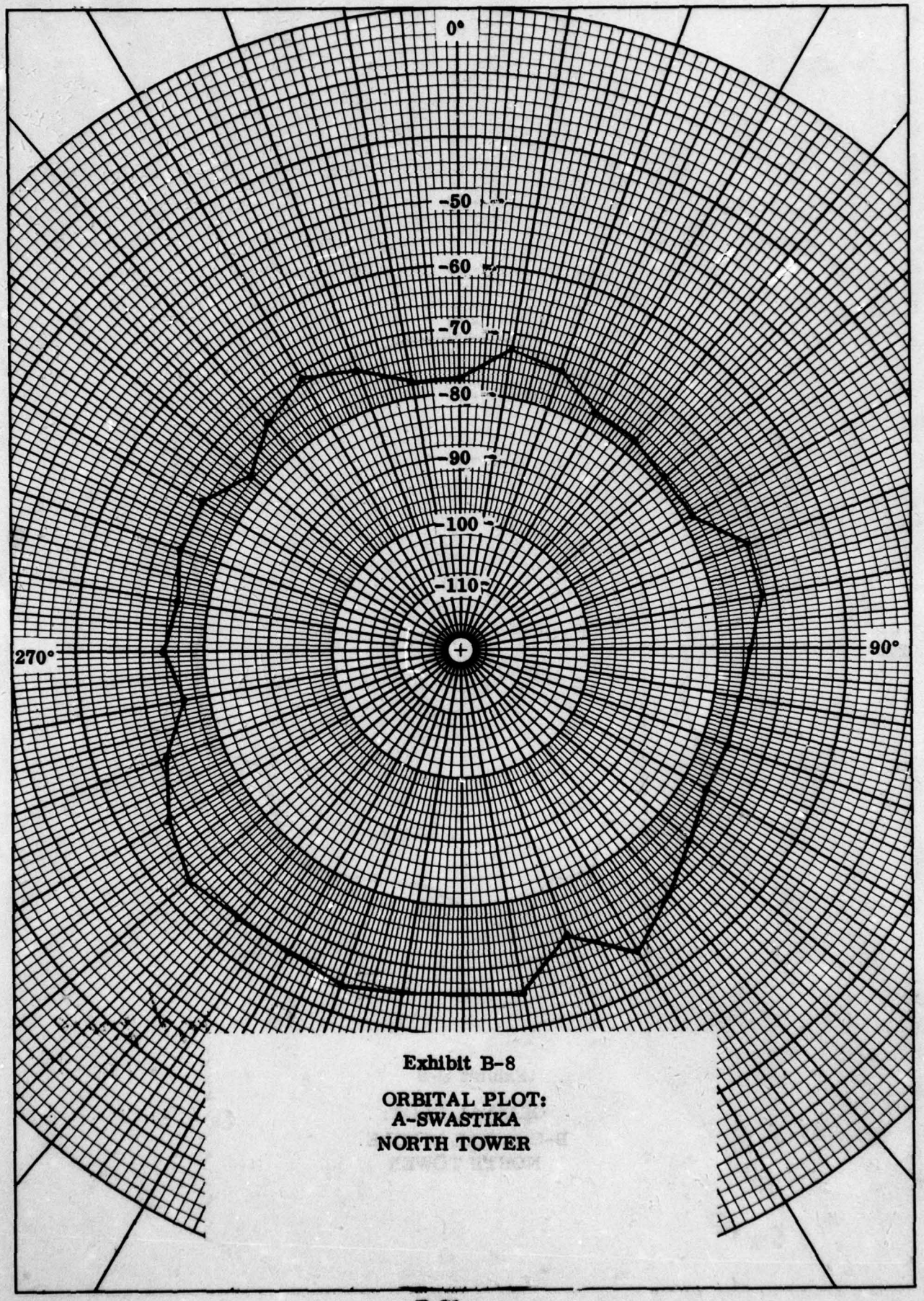


Exhibit B-8

ORBITAL PLOT:
A-SWASTIKA
NORTH TOWER

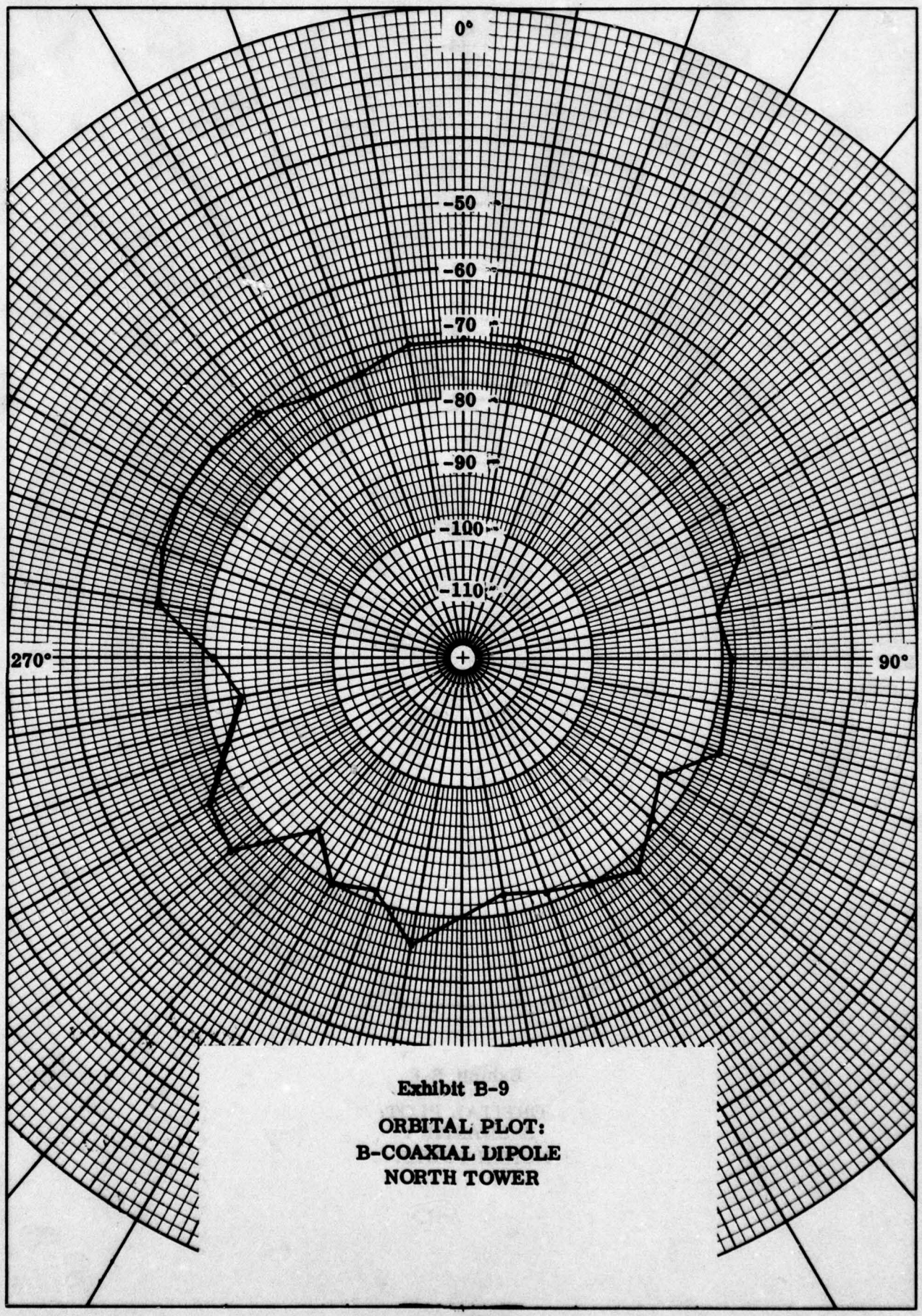


Exhibit B-9

ORBITAL PLOT:
B-COAXIAL DIPOLE
NORTH TOWER

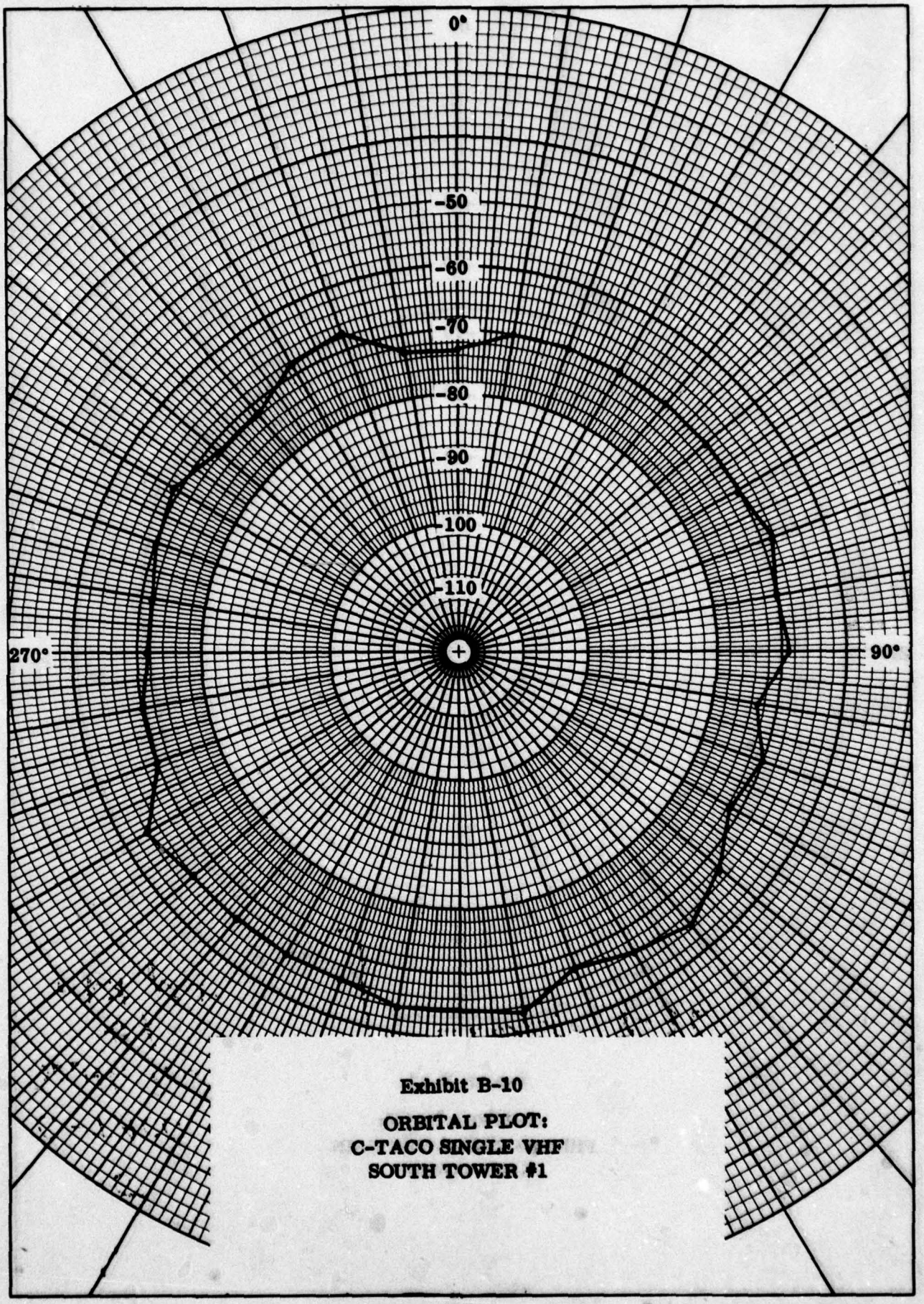


Exhibit B-10

ORBITAL PLOT:
C-TACO SINGLE VHF
SOUTH TOWER #1

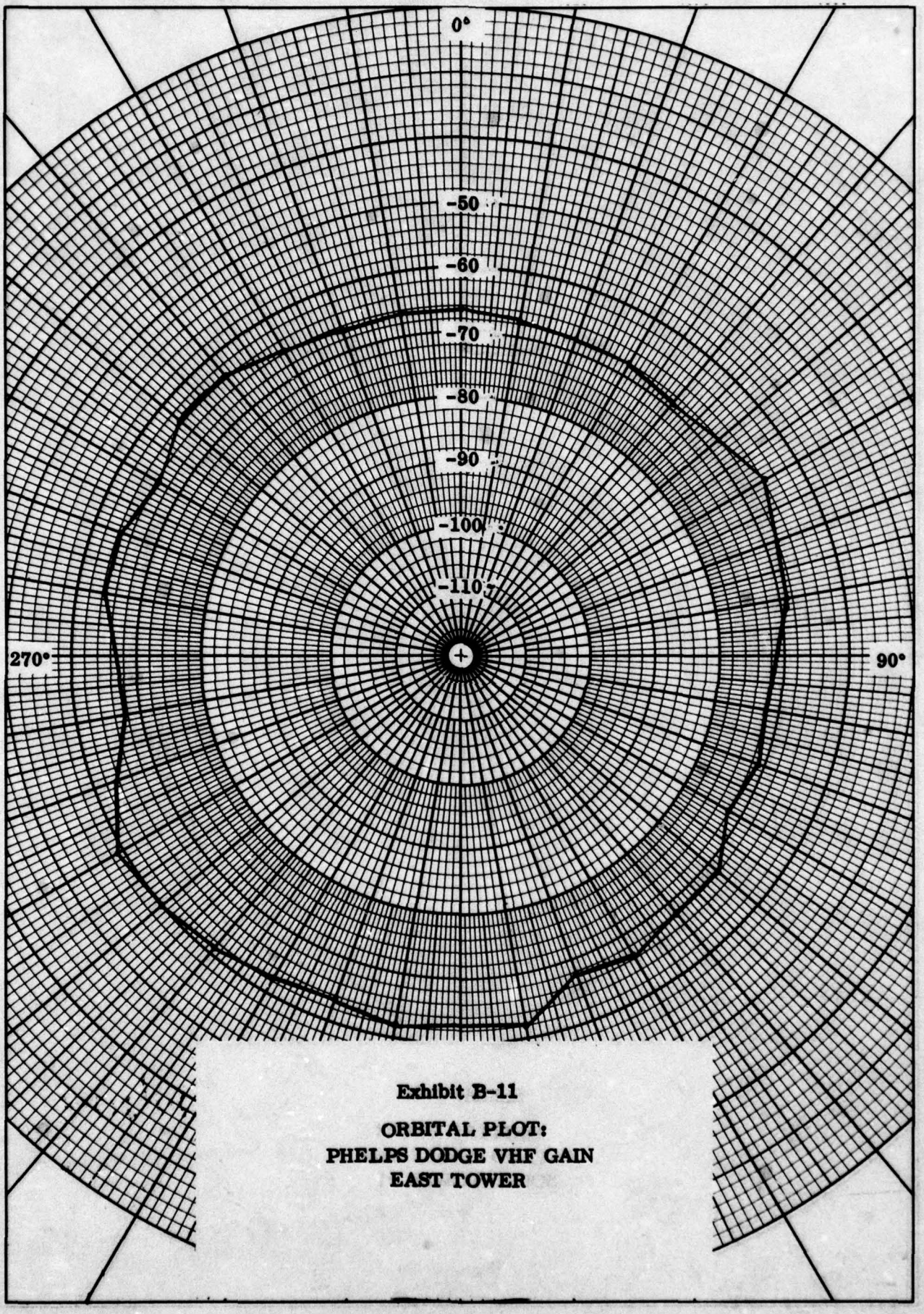


Exhibit B-11

ORBITAL PLOT:
PHELPS DODGE VHF GAIN
EAST TOWER

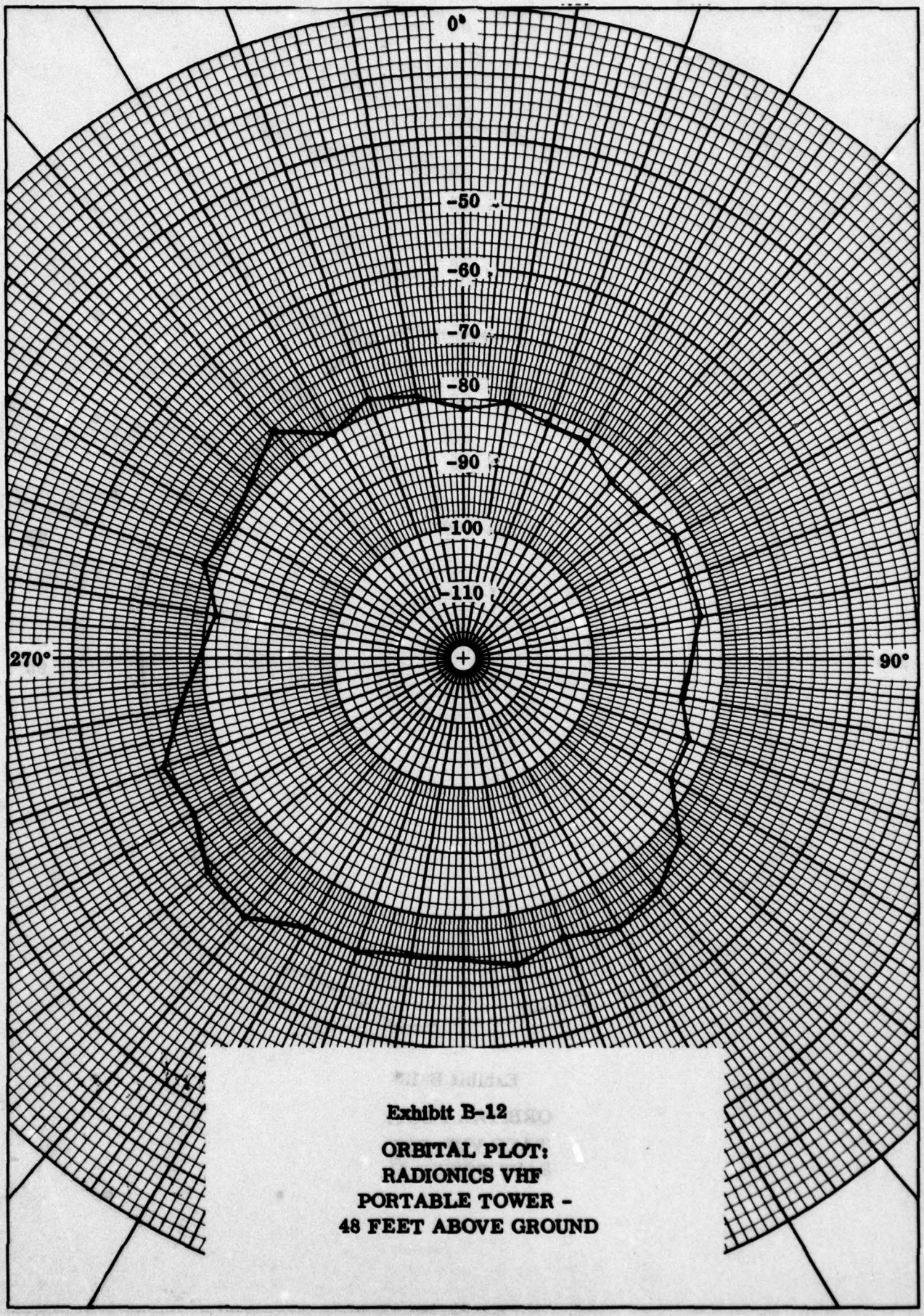


Exhibit B-12

ORBITAL PLOT:
RADIONICS VHF
PORTABLE TOWER -
48 FEET ABOVE GROUND

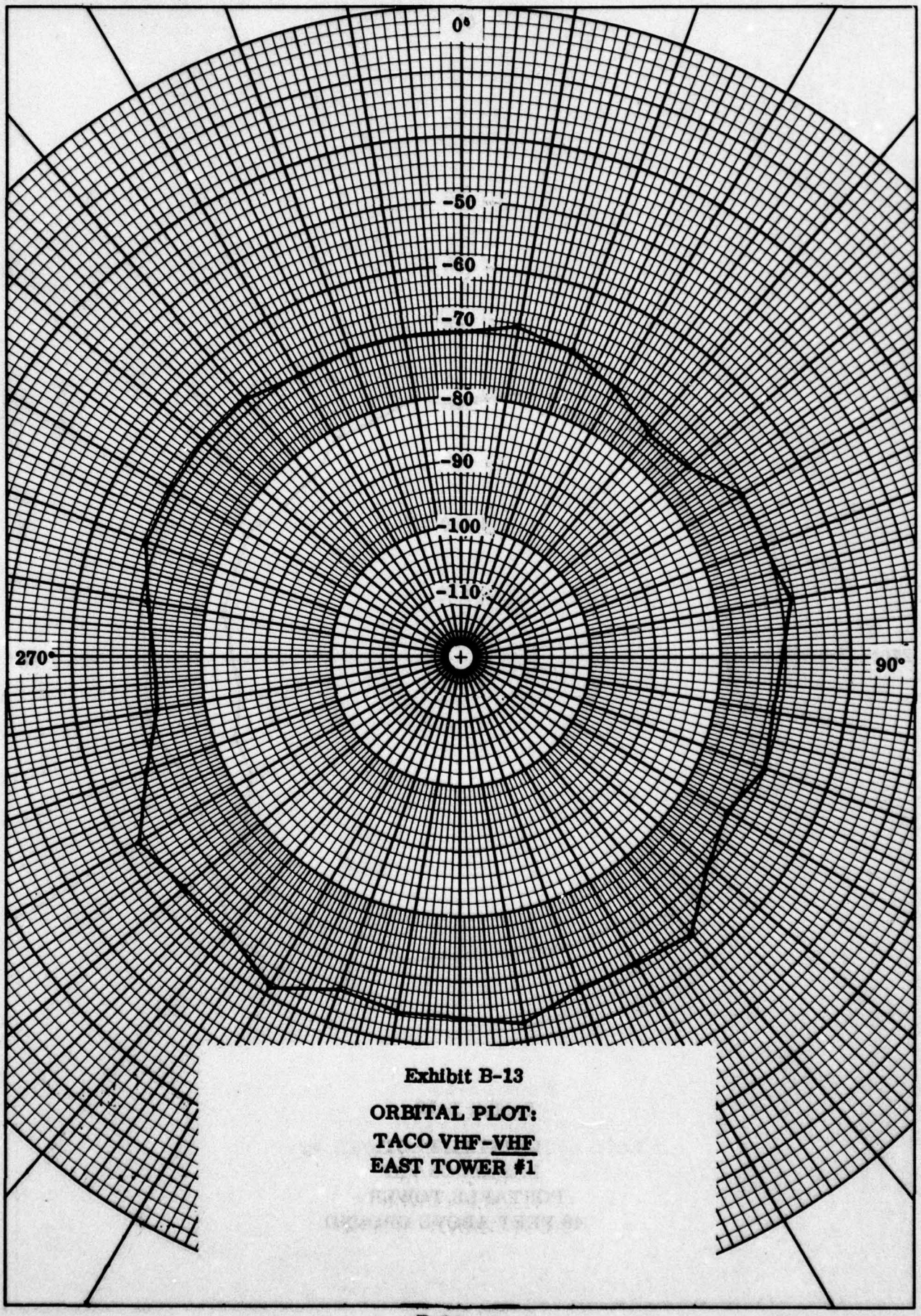


Exhibit B-13

ORBITAL PLOT:
TACO VHF-VHF
EAST TOWER #1

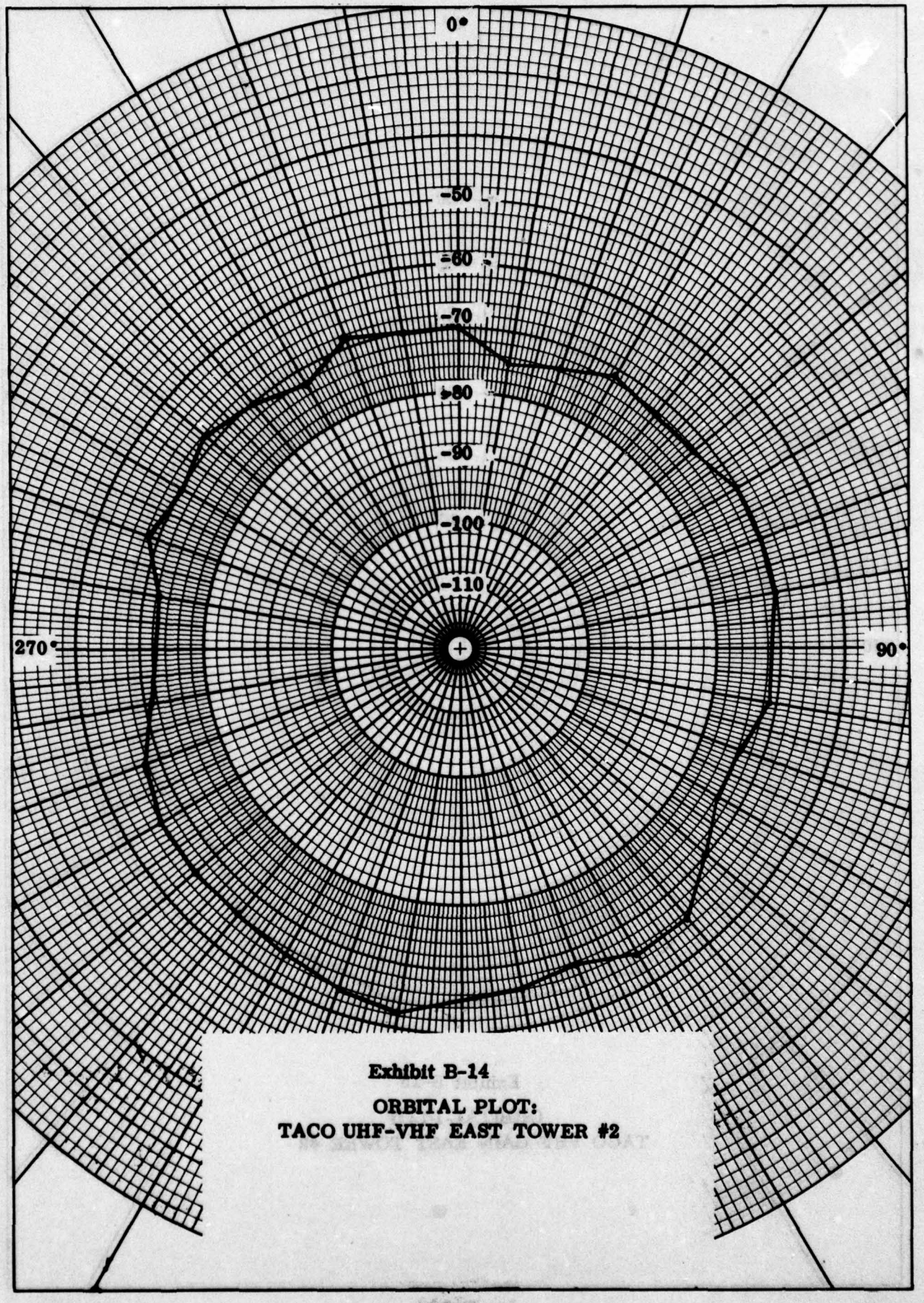


Exhibit B-14

ORBITAL PLOT:
TACO UHF-VHF EAST TOWER #2

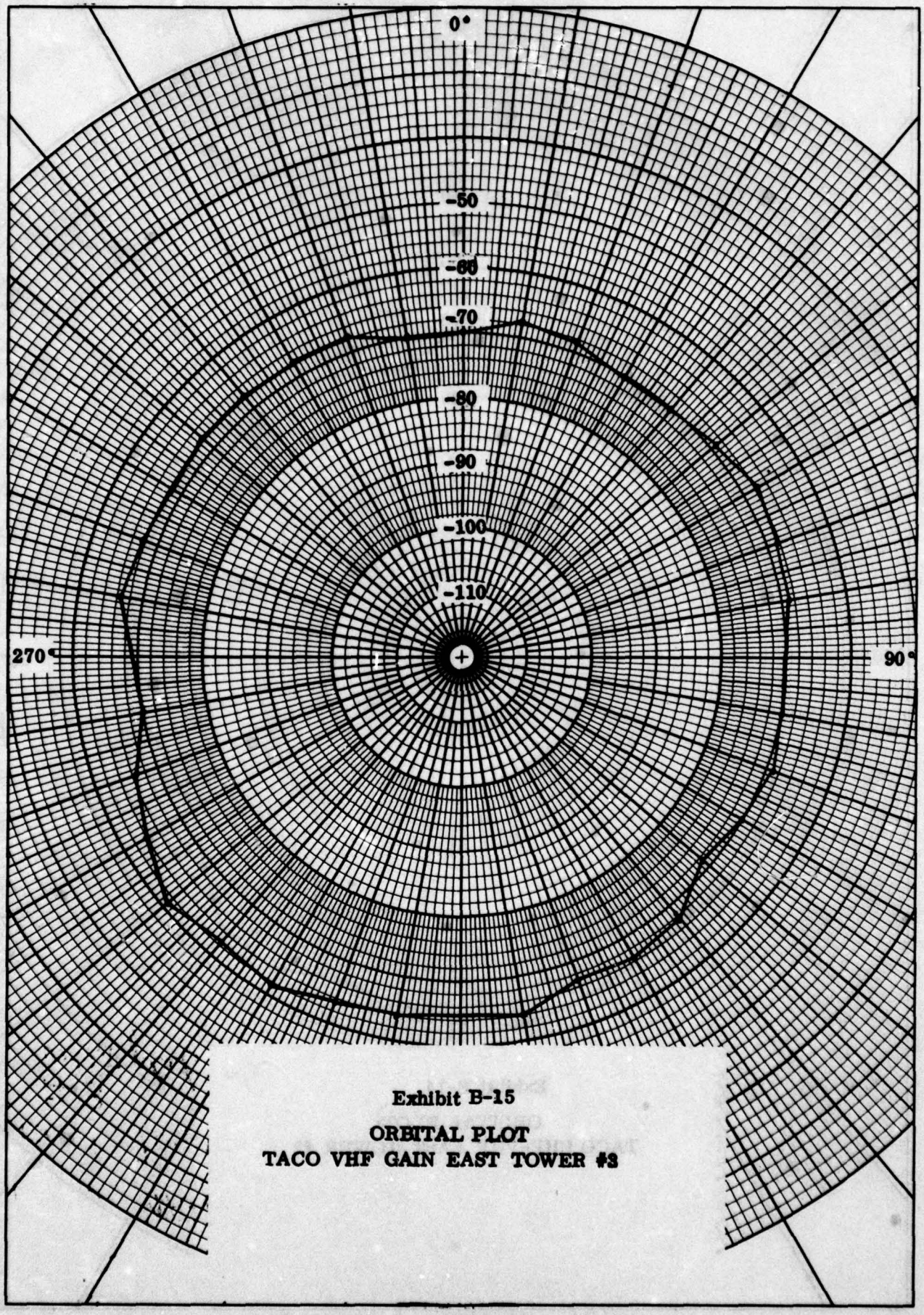


Exhibit B-15

ORBITAL PLOT
TACO VHF GAIN EAST TOWER #3

Exhibit B-16

RADIAL NO. 2 (EAST-WEST)

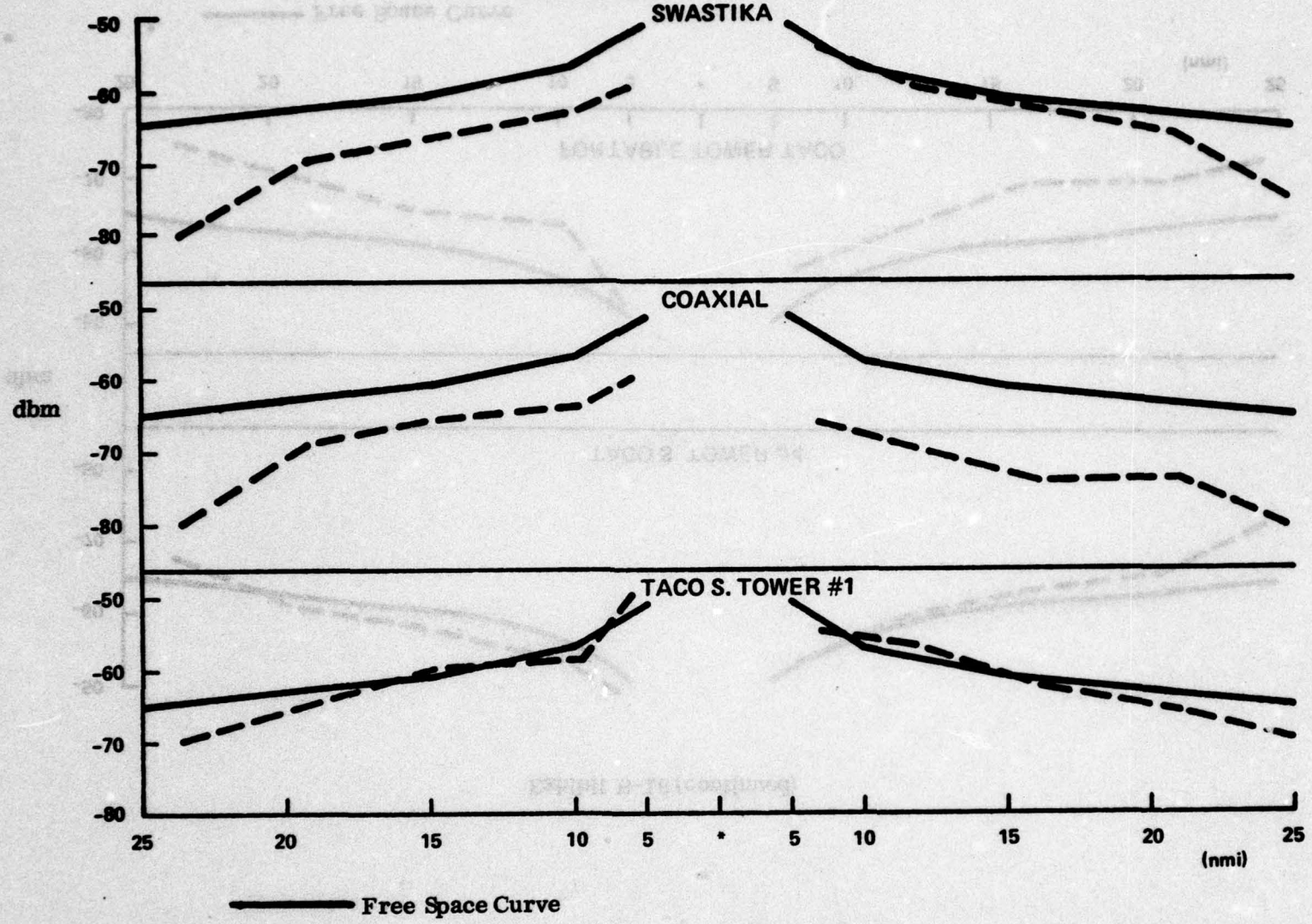


Exhibit B-16 (continued)

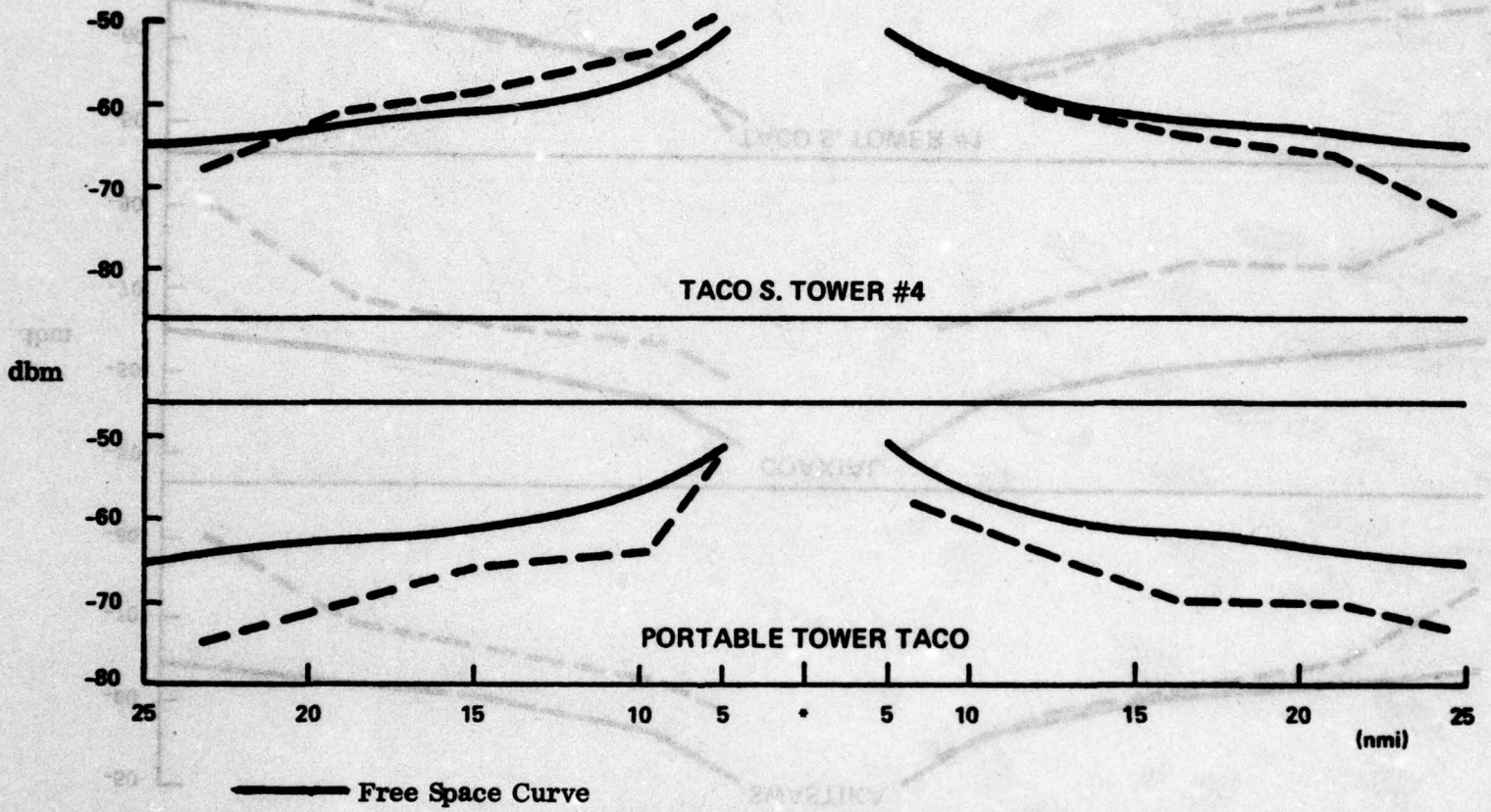


Exhibit B-17

RADIAL NO. 3 (NORTH-SOUTH)

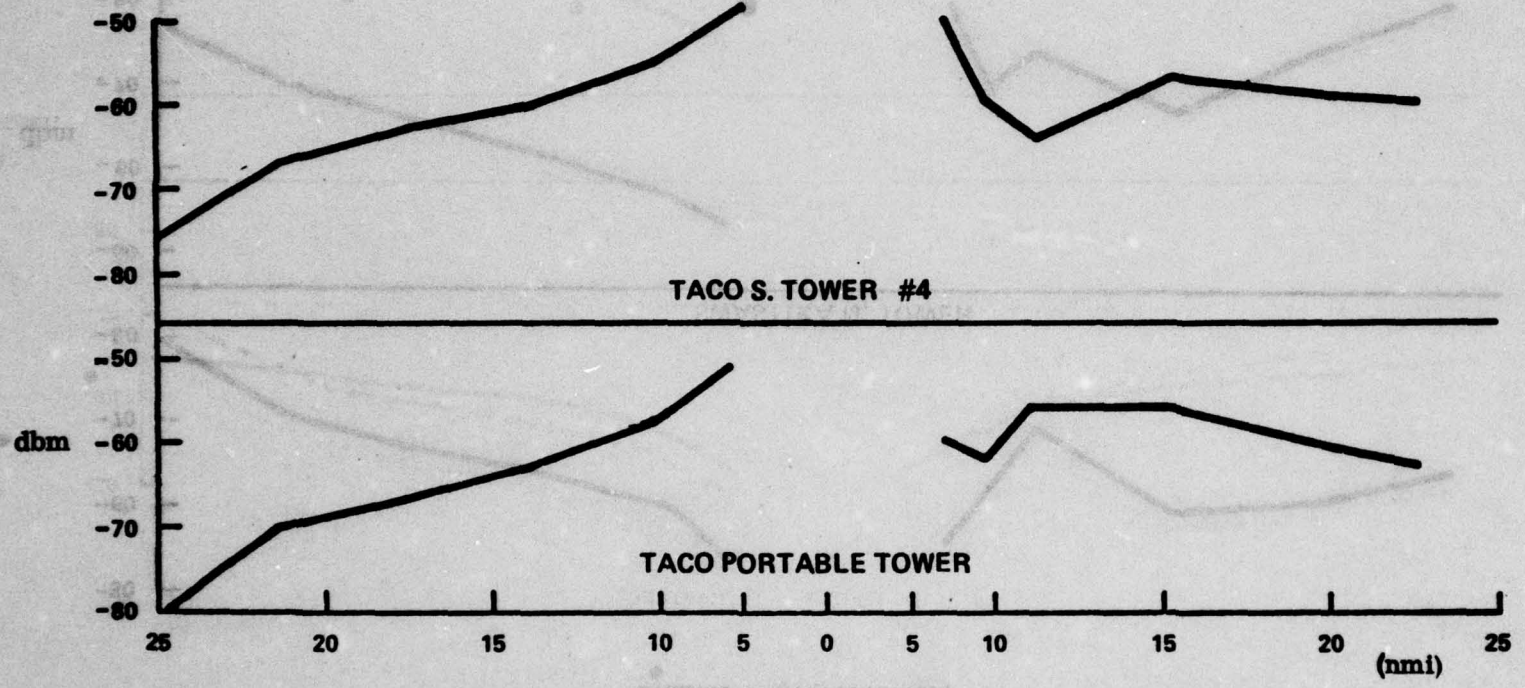


Exhibit B-17 (continued)

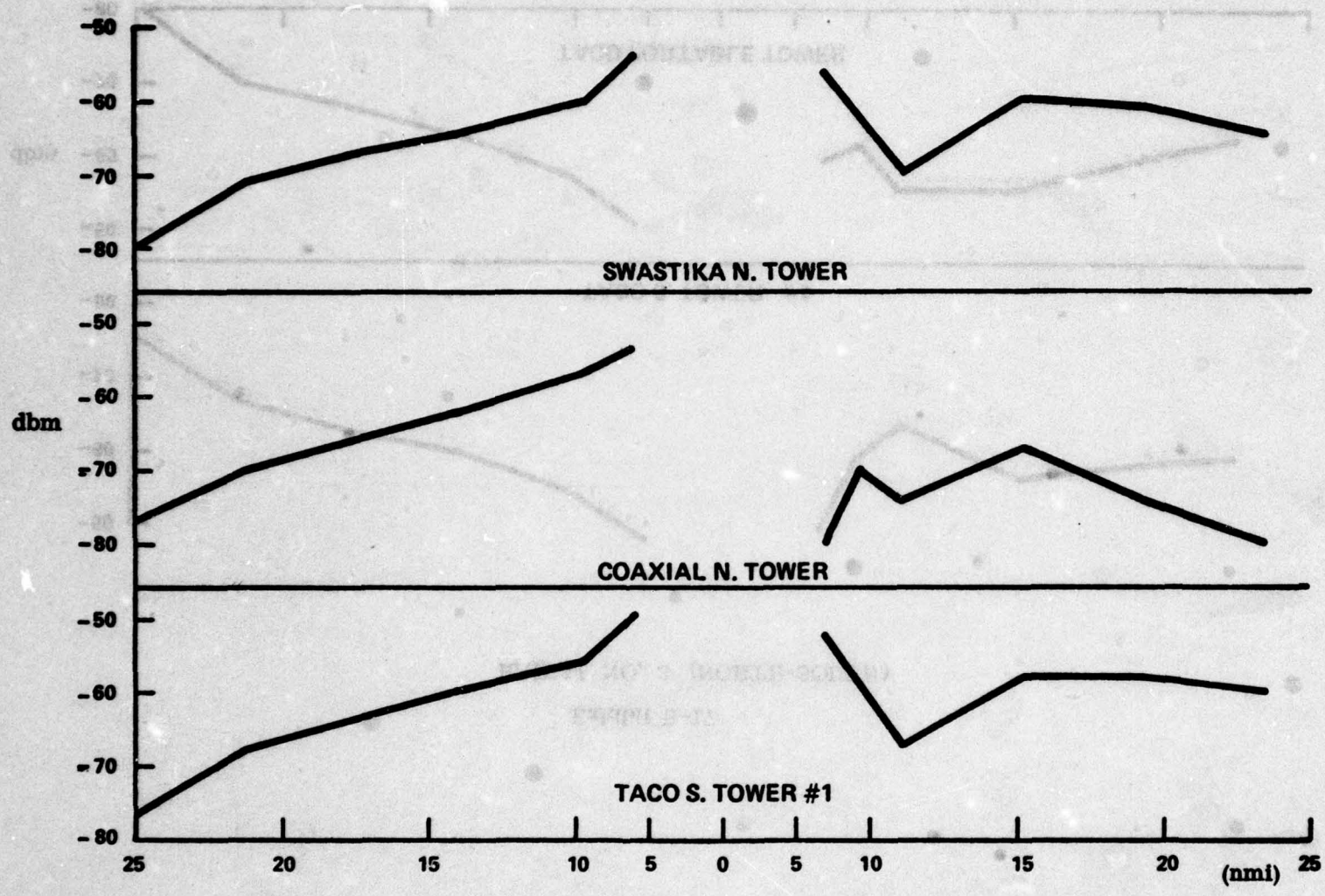


Exhibit B-18

RADIAL NO. 4 (WEST-EAST)

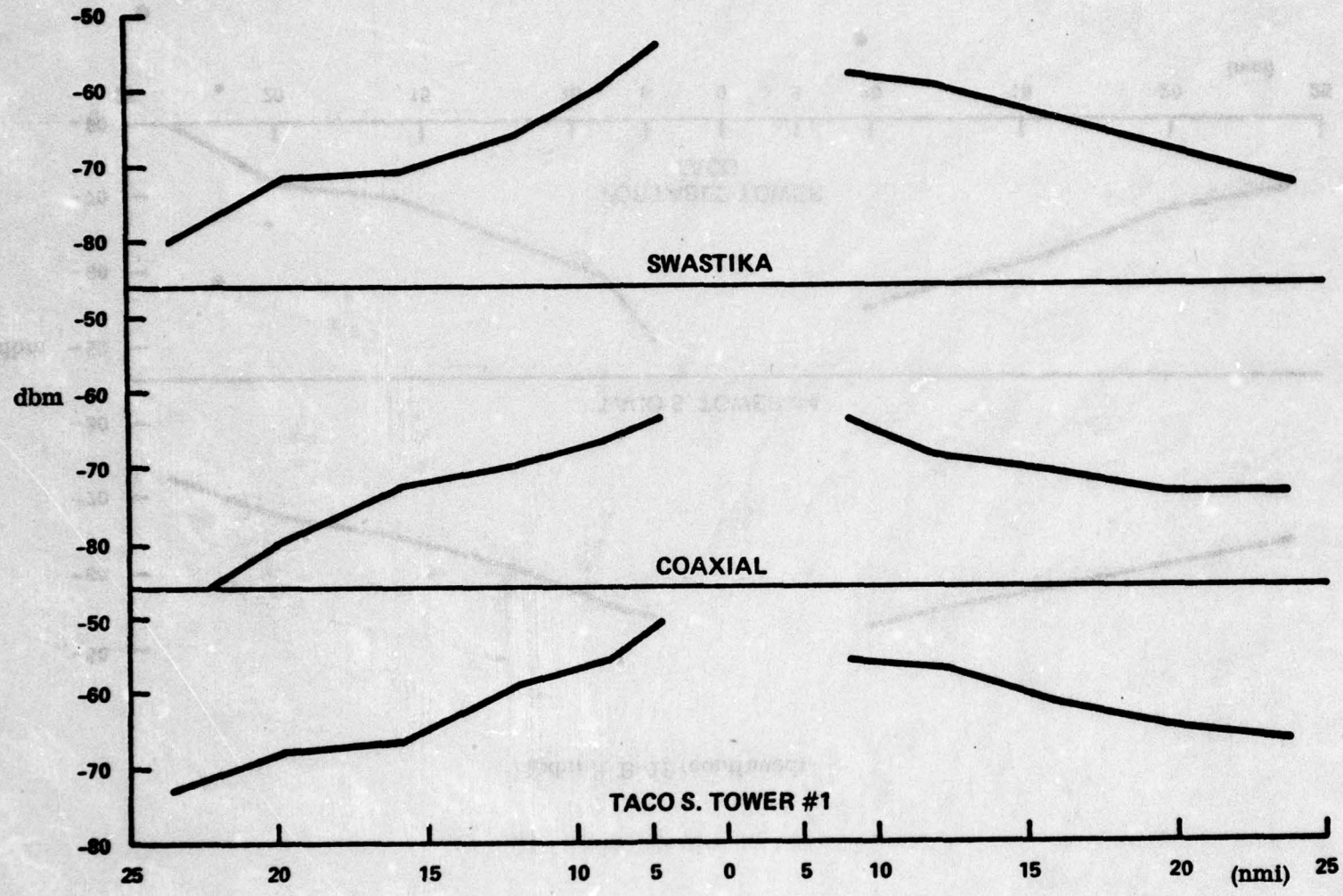
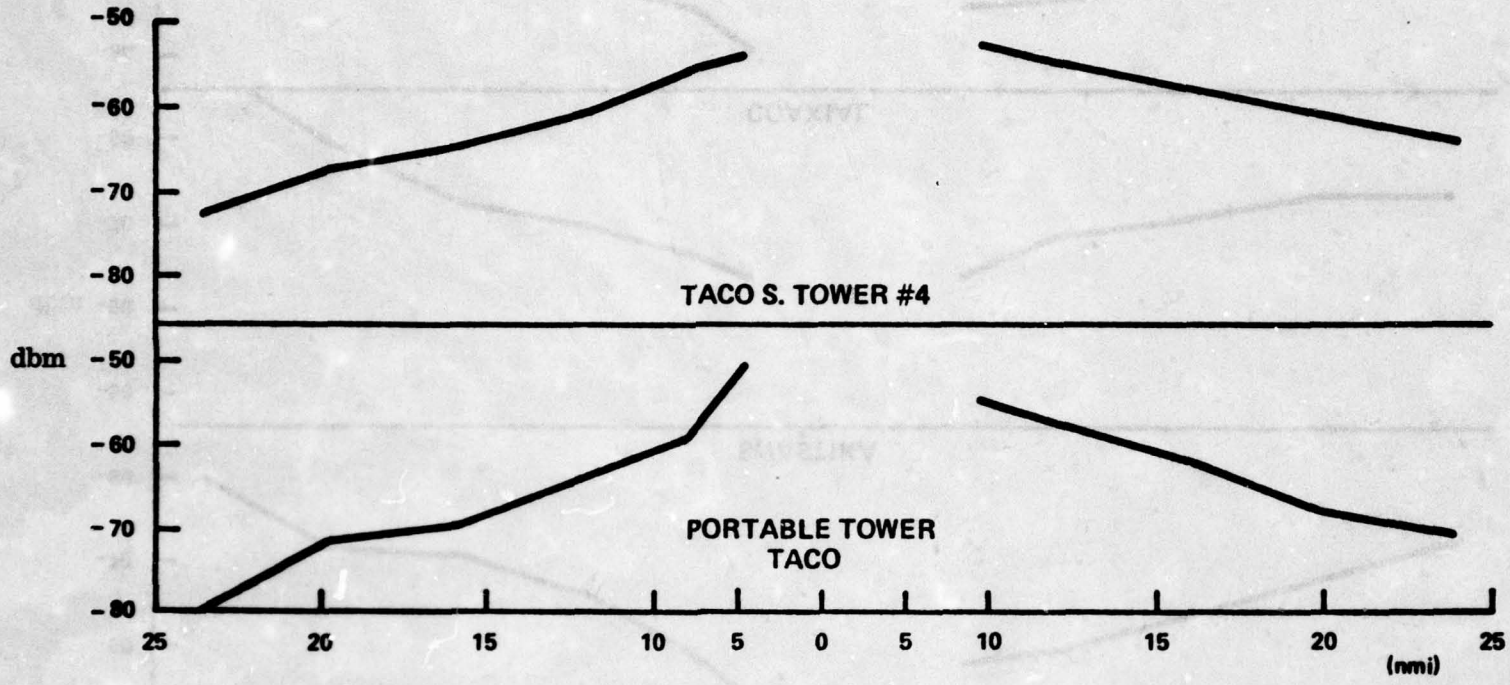
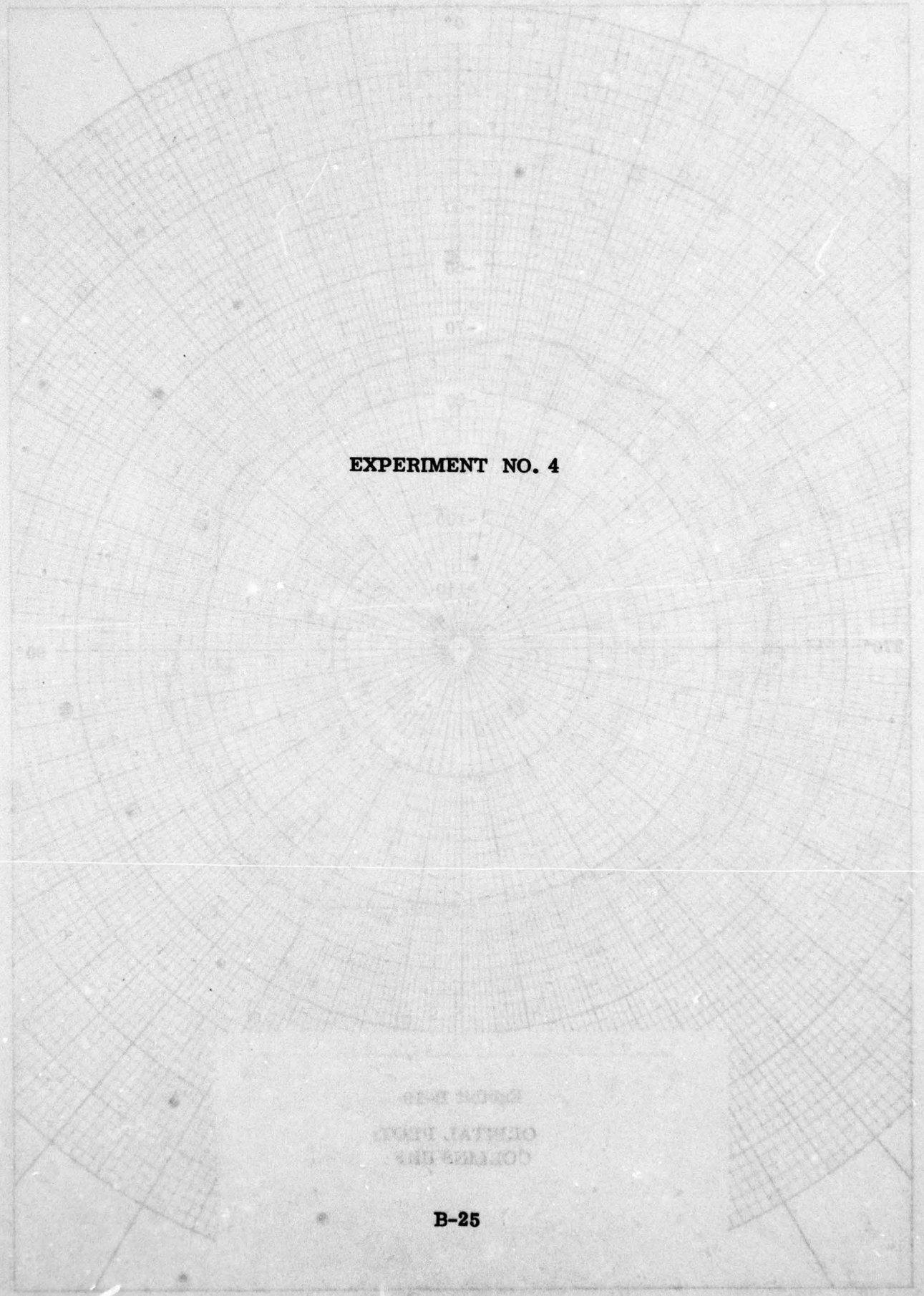


Exhibit B-18 (continued)





EXPERIMENT NO. 4

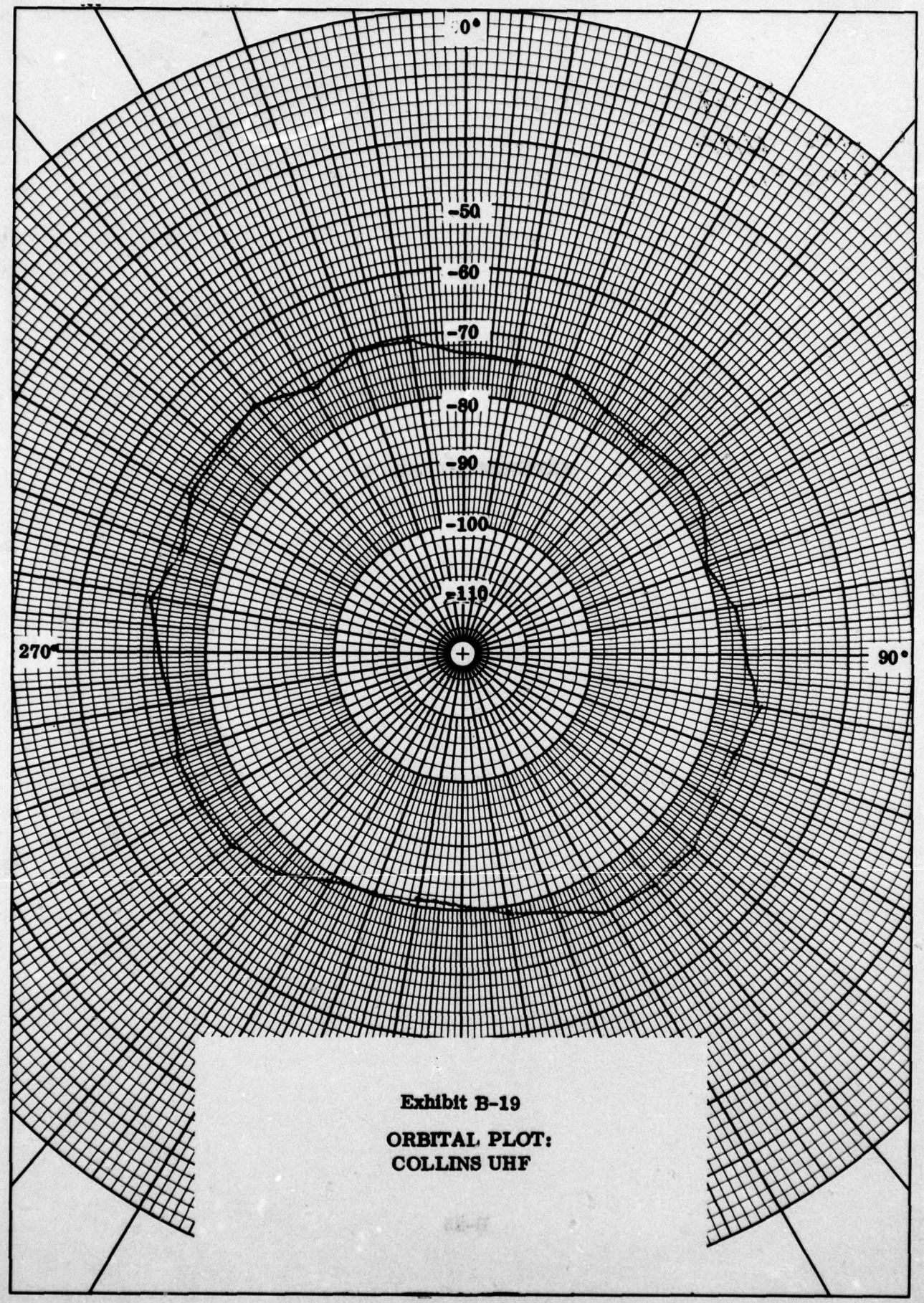


Exhibit B-19

ORBITAL PLOT:
COLLINS UHF

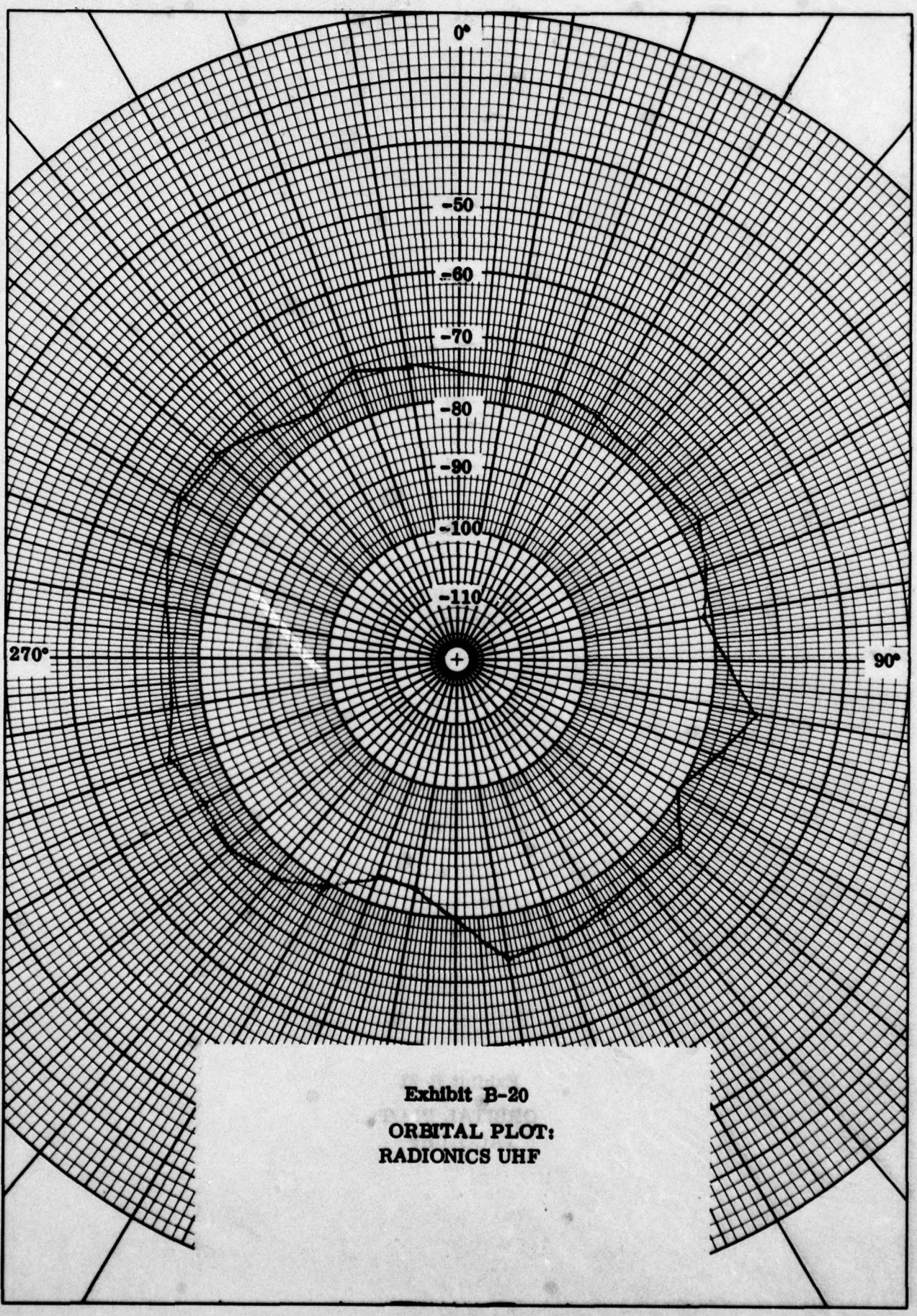


Exhibit B-20

ORBITAL PLOT:
RADIONICS UHF

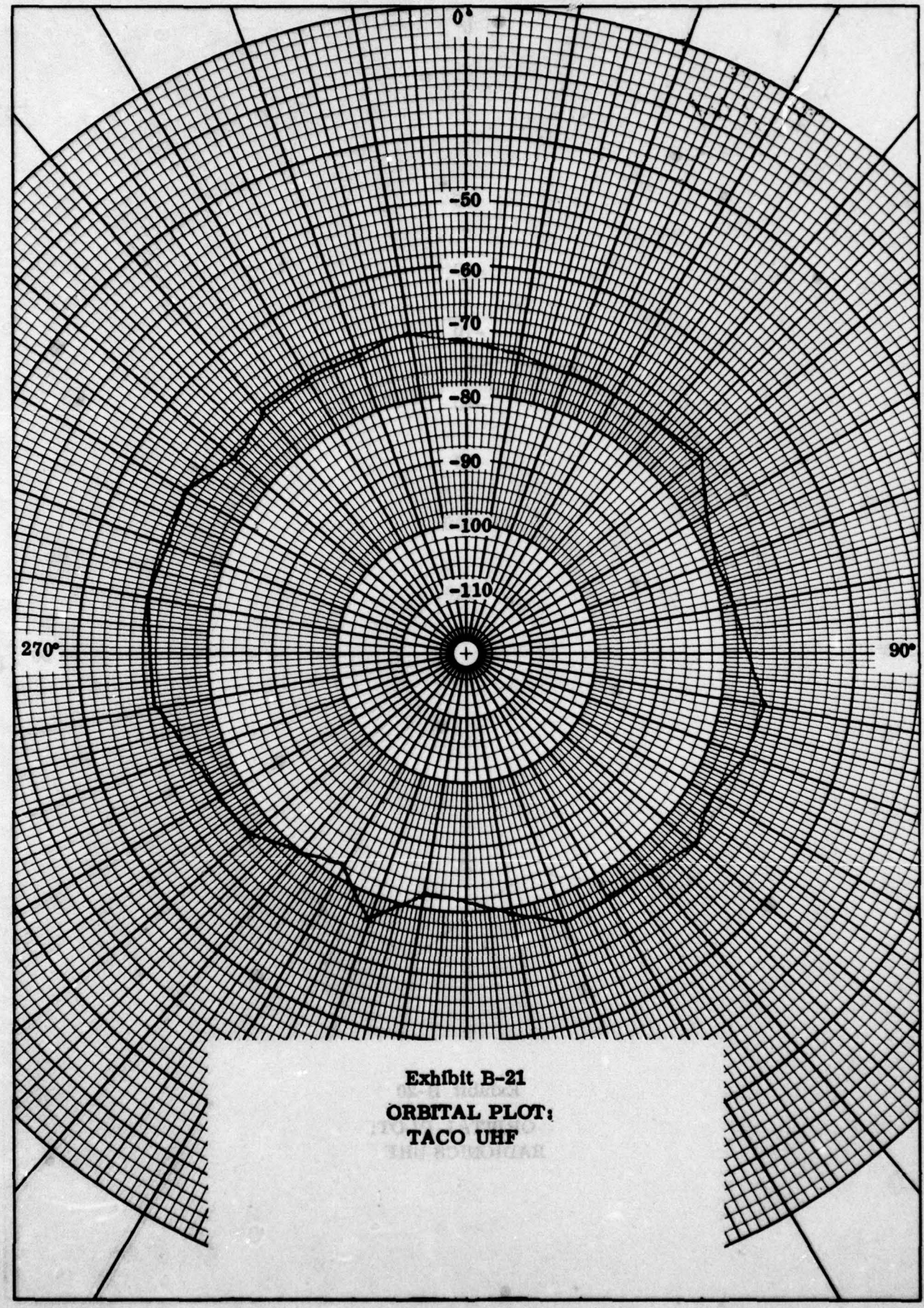


Exhibit B-21

ORBITAL PLOT:
TACO UHF

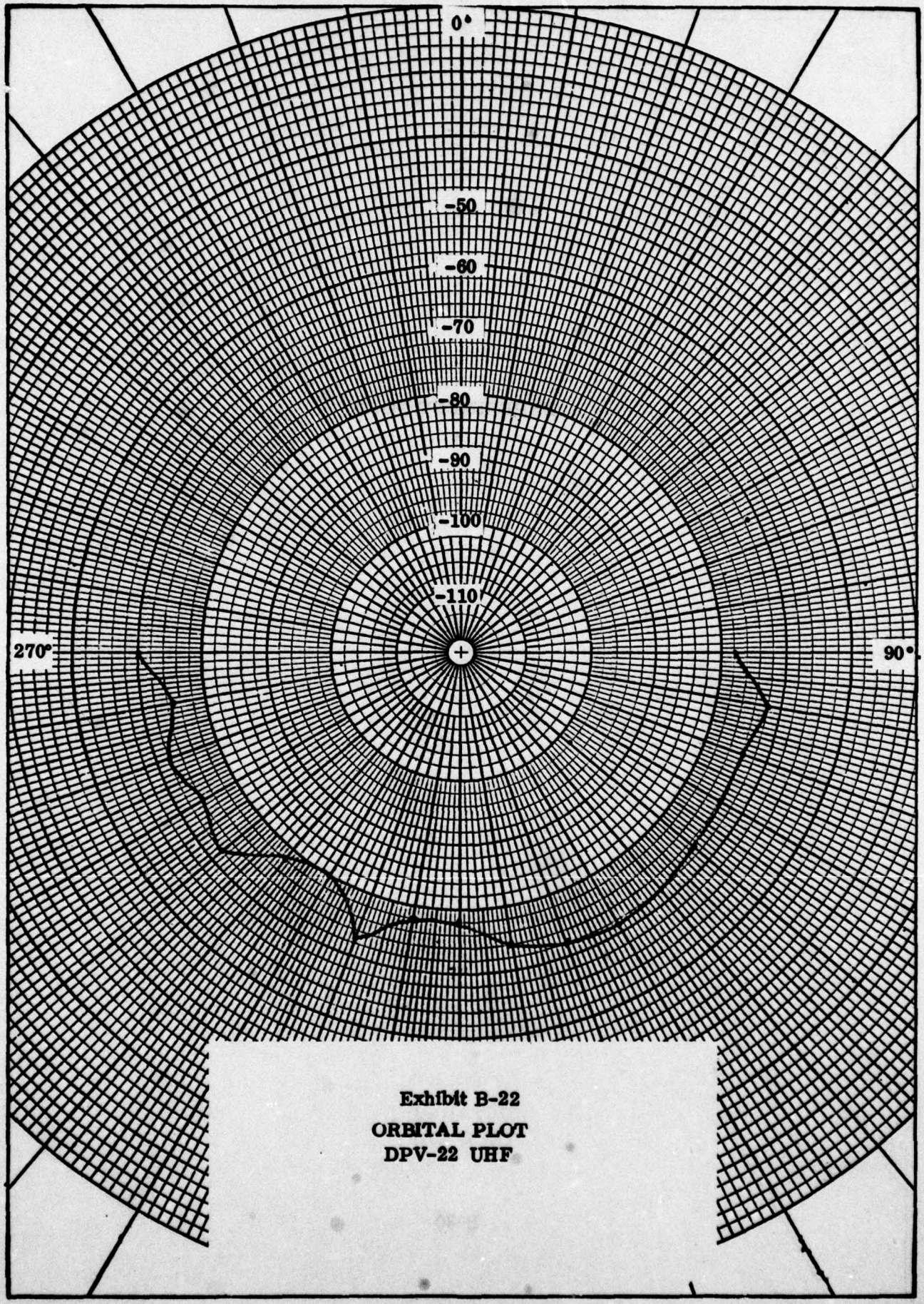
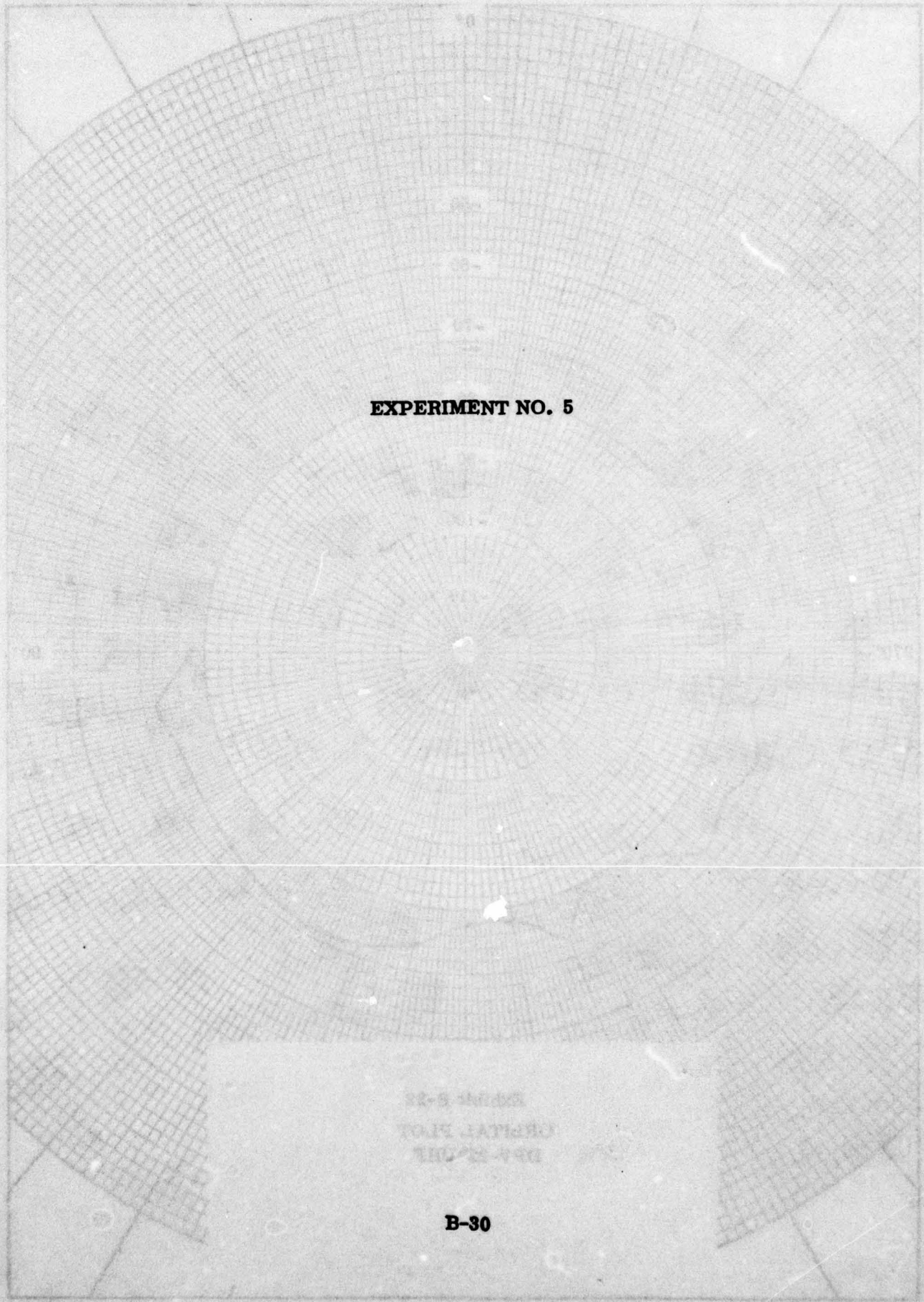


Exhibit B-22

ORBITAL PLOT
DPV-22 UHF



EXPERIMENT NO. 5

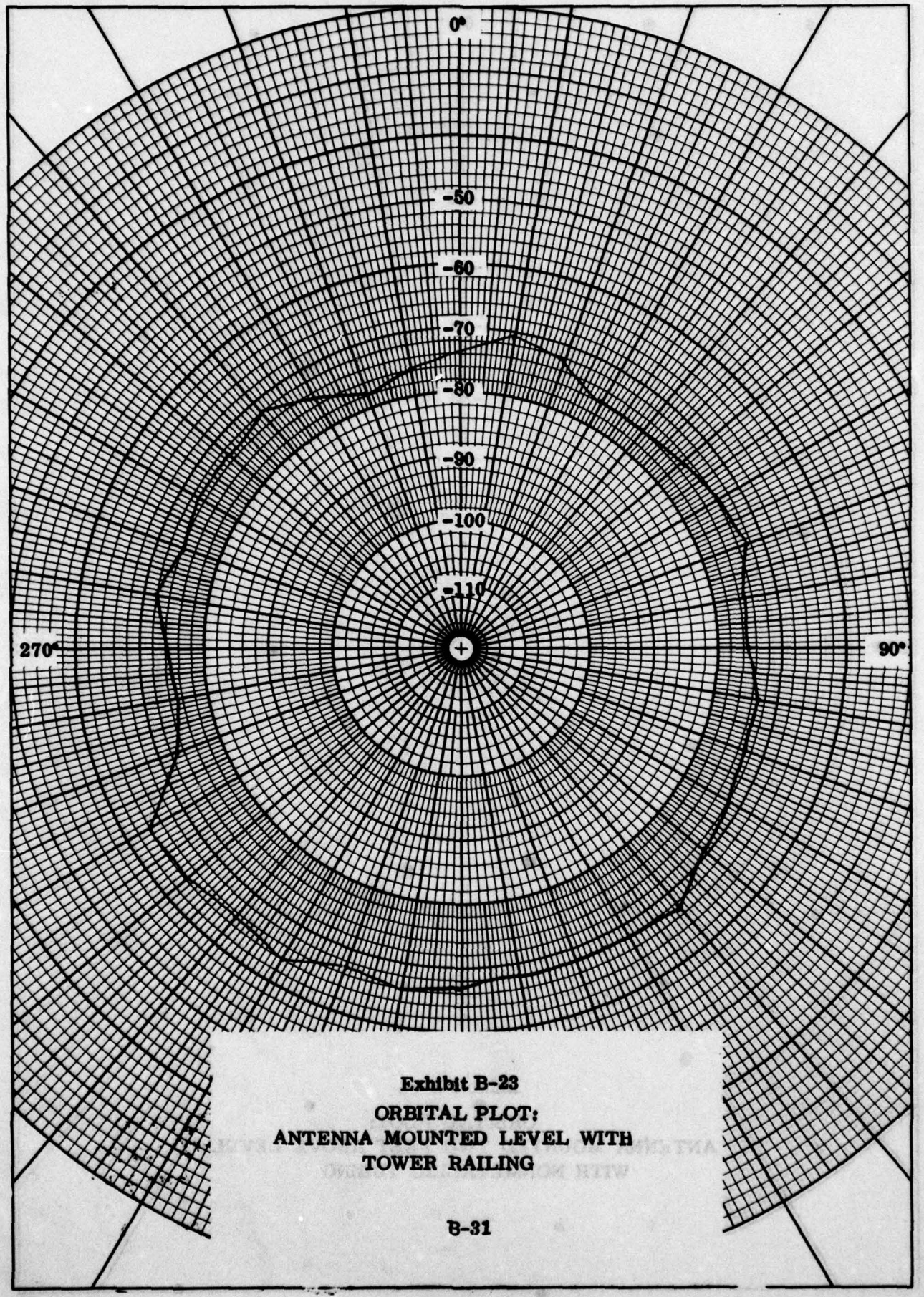


Exhibit B-23

ORBITAL PLOT:
ANTENNA MOUNTED LEVEL WITH TOWER RAILING

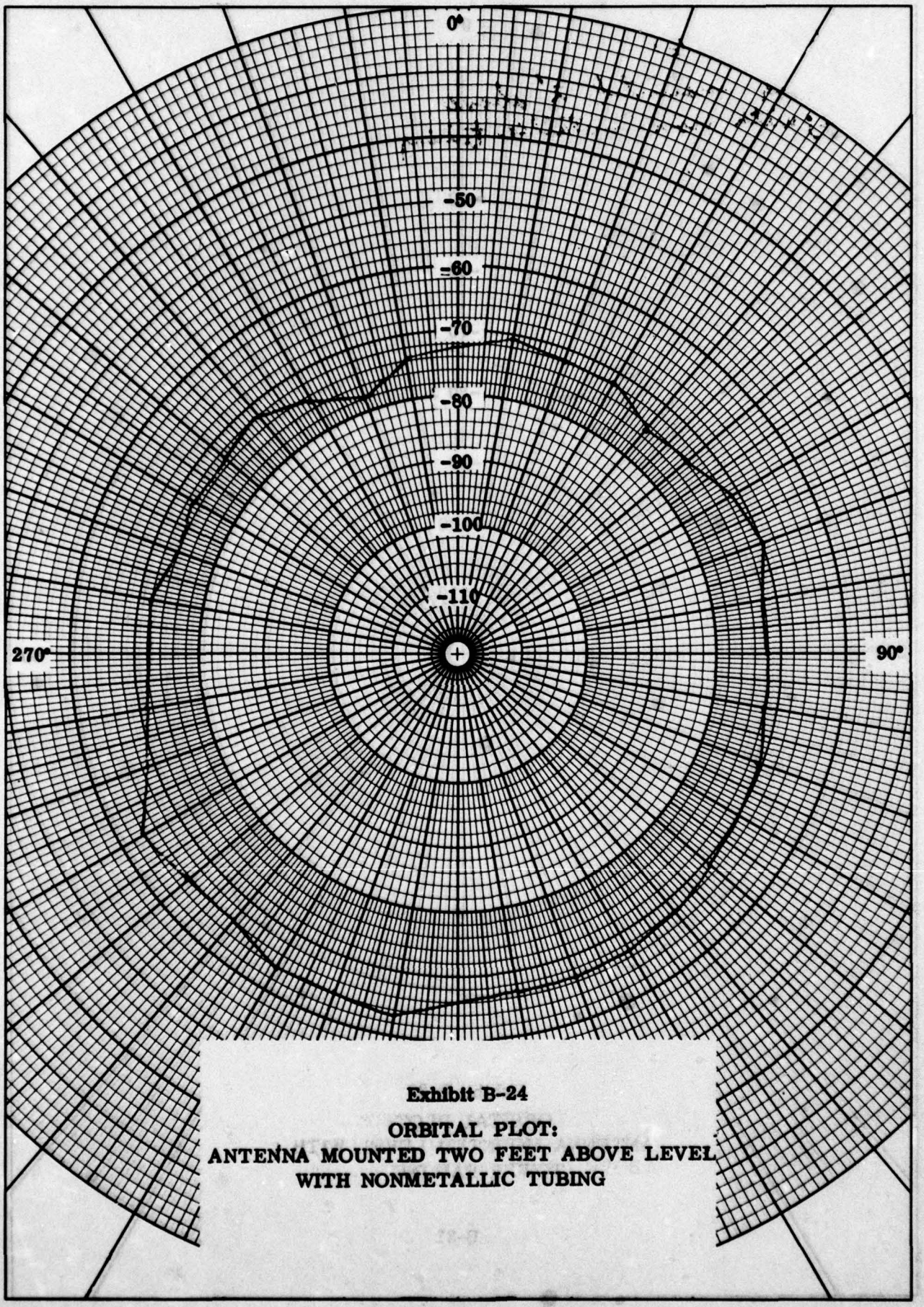


Exhibit B-24

ORBITAL PLOT:
ANTENNA MOUNTED TWO FEET ABOVE LEVEL
WITH NONMETALLIC TUBING

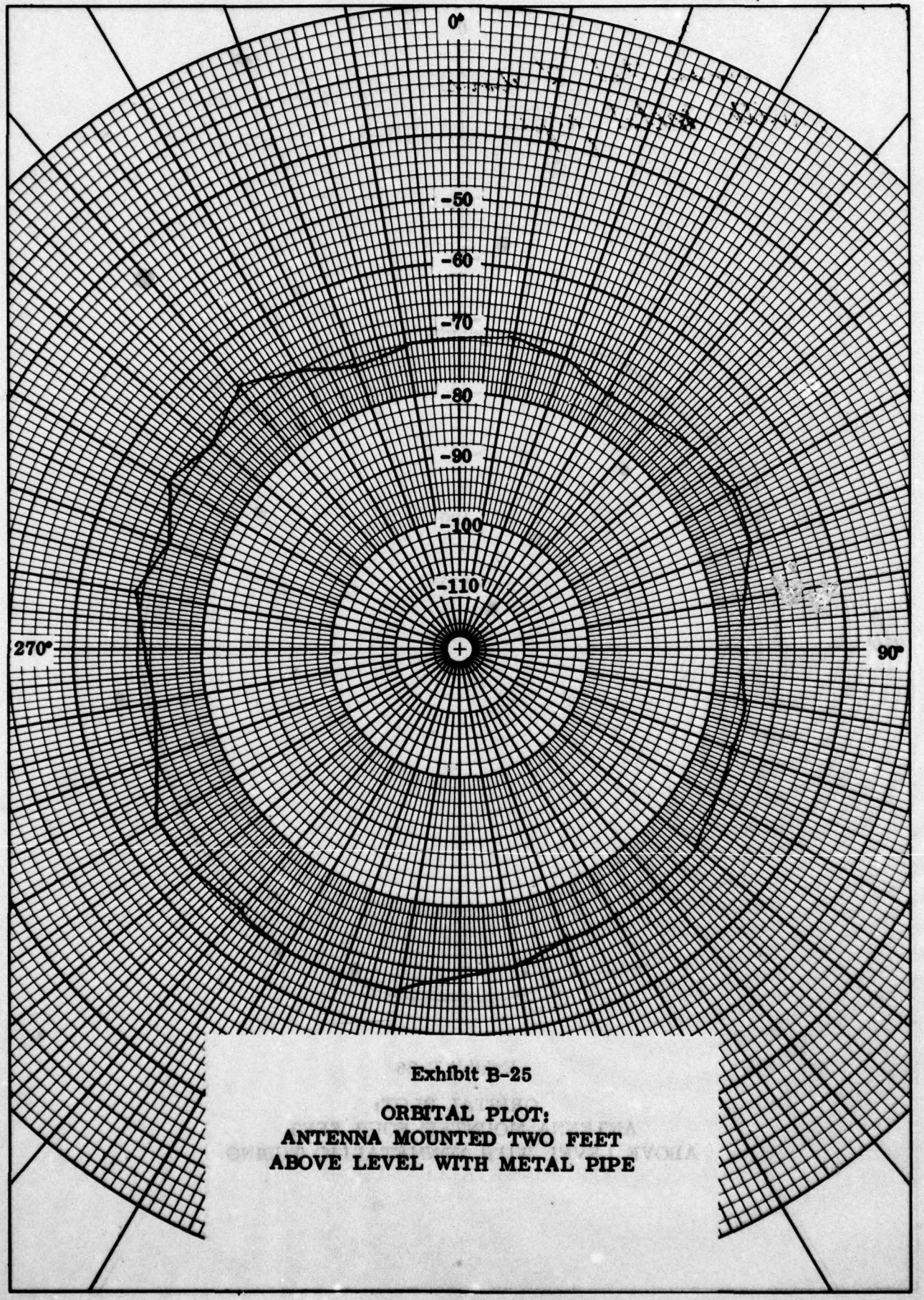


Exhibit B-25

ORBITAL PLOT:
ANTENNA MOUNTED TWO FEET
ABOVE LEVEL WITH METAL PIPE

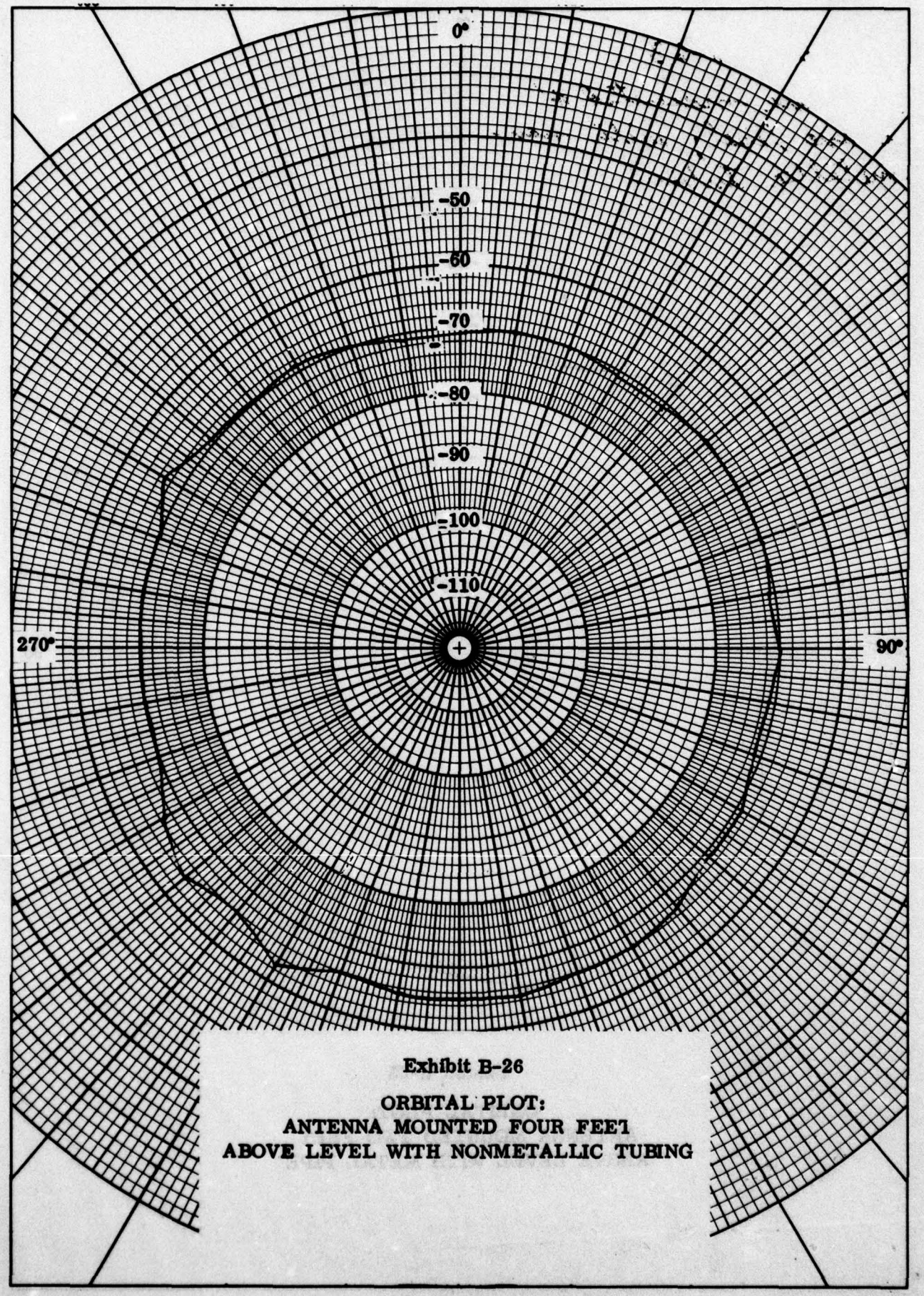


Exhibit B-26

ORBITAL PLOT:
ANTENNA MOUNTED FOUR FEET
ABOVE LEVEL WITH NONMETALLIC TUBING